

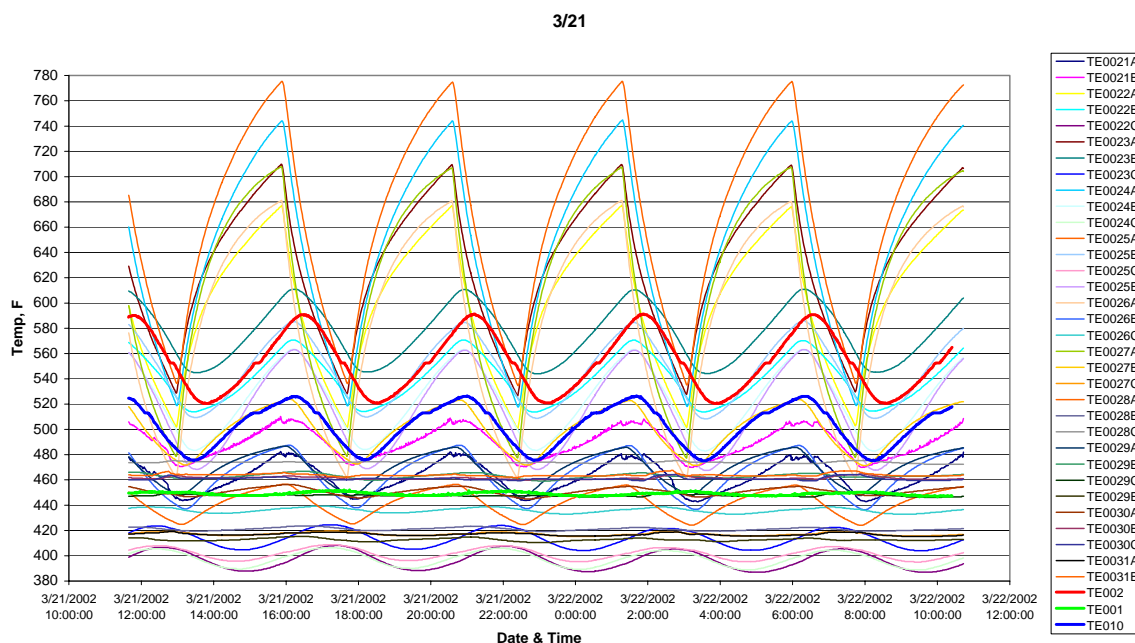


Phosphoric Acid Fuel Cells

Test and Evaluation

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October 2004



Fuel cells HDS temperature cycling.

Phosphoric Acid Fuel Cells: Test and Evaluation

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Final Report

Approved for public release; distribution is unlimited.

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000#

ABSTRACT: Fuel cell power plants can provide improvements in energy conservation and reduced environmental impacts for many DOD applications. Currently, the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL) Fuel Cell Technology Program facilitates the development of Fuel Cell Technology. This work provided testing and evaluations of fuel cells in support of life-cycle-cost reduction and performance improvement goals. This program also undertook to provide the capability for independent design assessments of alternative technology fuel cell system configurations and components to achieve lower life cycle cost either through reduced capital cost, reduced operation and maintenance (O&M) costs, or increased performance and reliability.

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Conversion Factors

Non-SI* units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	$(5/9) \times (^\circ\text{F} - 32)$	degrees Celsius
degrees Fahrenheit	$(5/9) \times (^\circ\text{F} - 32) + 273.15$	kelvins
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

* *Système International d'Unités* ("International System of Measurement"), commonly known as the "metric system."

Preface

This study was conducted for the Office of the Director, Defense, Research, and Engineering (ODDR&E), under Work Unit number, 006G7B, "Climate Change Fuel Cells." The technical monitor was Mr. Bob Boyd, ODDR&E.

The work was performed by the Energy Branch (CF-E), of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigators were Michael J. Binder and Franklin H. Holcomb. Part of this work was done by Concurrent Technologies Corporation (*CTC*), Johnstown, PA under National Defense Center for Environmental Excellence (NDCEE) Task Order N.211, Contract No. DAAE30-98-C-1050. Robert J. Unger and Scott Kenner are associated with CTC. The technical editor was William J. Wolfe, Information Technology Laboratory. Dr. Thomas Hartranft is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Technical Director was Gary W. Schanche, CEERD-CVT. The Director of CERL is Dr. Alan W. Moore.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James Rowan, EN and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Background

Fuel cell power plants can provide improvements in energy conservation and reduced environmental impacts for many Department of Defense (DOD) applications. In fiscal year 1993 (FY93), Congress appropriated \$18 million to advance the use of phosphoric acid fuel cell (PAFC) power plants at DOD installations. An additional \$18.75 million was appropriated in FY94 to expand the program. The Army, Air Force, and Navy/Marine Corps each received \$6 million for the purchase, installation, and operation of the fuel cell power plants in FY93, and \$6.25 million in FY94. By November 1997, DOD had installed 30 PAFC power plants throughout the continental United States and Alaska. The program has successfully demonstrated the capability of the PAFC technology by generating more than 101,977 MWh of electricity through September 2000.

The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL) managed this program. CERL's activities included developing turnkey PAFC packages, devising site selection criteria, screening DOD candidate installation sites using selection criteria, evaluating viable applications at each candidate site, coordinating fuel cell site designs, overseeing installation and acceptance of the power plants, and monitoring and reporting the performance of the fleet. Information on the program is available through the world-wide web (WWW) at:

<http://www.dodfuelcell.com>

Currently, the ERDC/CERL Fuel Cell Technology Program facilitates the development of Fuel Cell Technology to achieve performance and cost goals expeditiously and provide a means to deploy technology improvements while maintaining reliability. This work provided testing and evaluations, in cooperation with United Technologies Corp. (UTC) Fuel Cells of a PC25C. This test and evaluation effort was undertaken to support life-cycle-cost reduction and performance improvement goals. This program also undertook to provide the capability for independent design assessments of alternative technology fuel cell system configurations and components for achieving lower life cycle cost either through re-

duced capital cost, reduced operation and maintenance (O&M) costs, or increased performance and reliability.

Objective

The objective of this work was to test and evaluate a UTC Fuel Cells 200 kilowatt (kW) PC25C Phosphoric Acid Fuel Cell Power Plant (PAFC) to achieve life-cycle-cost reduction and performance improvements.

Approach

In this work researchers:

2. Designed and constructed the Department of Defense (DOD) Fuel Cell Test and Evaluation Center (FCTec) within the Environmental Technology Facility (ETF) at Concurrent Technologies Corporation (CTC), a National Resource for the independent, unbiased testing and validation of fuel cell power plants for military and commercial applications. This included the acquisition and installation of testing equipment within the FCTec to support PC25C testing and evaluation.
3. Acquired and installed an UTC Fuel Cells 200 kW PC25C Phosphoric Acid Fuel Cell Power Plant with customized capabilities for supporting the test objective.
4. Acquired and installed testing equipment within the FCTec for the support of AVISTA SR 12 modular PEM generator and similar smaller fuel cell power plant systems.
5. Provided testing to support the performance improvement objectives of the ERDC/CERL fuel cell program.

Scope

This work focused on the testing and evaluation of UTC Fuel Cells 200 kW PC25C PAFC Power Plant.

Mode of Technology Transfer

It is anticipated that the material collected and developed during this study may be presented in workshops and as a Proponent Sponsored Engineer Corps Training (PROSPECT) course through the Corps of Engineers, Huntsville Engineering

and Support Center. This material will also be made publicly available through the world-wide web at: www.cecercer.army.mil

2 Summary of Completed Tests

Ten tests were performed by *CTC* on the PC25C. Several of the tests required re-valuation and re-testing to assure proper results. Two of the originally scheduled tests were not performed because of changes in scope of UTC Fuel Cells and ERDC/CERL. The development of a web based FTP site allowed for the quick transfer of large test data files to the fuel cell manufacturers as well as to ERDC/CERL. The test data has been transmitted to both UTC Fuel Cells and ERDC/CERL via the *FCTec* FTP site.

Modification 1 Additional Activities

Emissions BT001C

Objective

CTC performed exhaust emission sampling on the PC25C during the new base-line power plant evaluation. This test evaluated the level of emissions released from the PC25C during operation on natural gas. The measured values allow for comparison to past PC25C fuel cell emission data from the initial testing performed at the start up of the system.

Activity

The emission output from the power plant was monitored and tested during operation with 100 percent utility natural gas. The power plant was operated in the grid-connect mode with no customer heat recovery, at 100 kW and 200 kW power levels. The test methods used for all test parameters conform to Environmental Protection Agency (EPA) protocols. These methods included Method 1 for location of sampling ports and Method 2 for measuring velocities in a stack. The following instrumental procedures were used as well:

- *Method 1* Sample and Velocity Traverse for Stationary Sources
- *Method 2C* Determination of Stack Gas Velocity and Volumetric Flow Rate in small Stacks (standard Pitot tube)
- *Method 3* Determination of O₂ and CO₂ Concentrations in Emissions from Stationary Sources

- *Method 3A* Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources
- *Method 4* Determination of Moisture Content in Stack Gases
- *Method 7E* Determination of Nitrogen Oxide Emissions from Stationary Sources (Instrument Analyzer Procedure)
- *Method 10* Determination of Carbon Monoxide from Stationary Sources
- *Method 18* Measurement of Gaseous Organic Compound Emissions by Gas Chromatography
- *Method 25A* Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer.

Conclusion

The test results were documented to allow for future comparison. The test was performed to monitor carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOC), total hydrocarbons (THC), and sample temperatures. Excess oxygen (O₂) was also measured at the Power Plant exhaust during the monitoring period (Table 1). The system emission output is unchanged from the initial start up at the beginning of system life. Some values appeared to be lower at mid life testing of the power plant system. These values are indicative of the use of measurement devices during the second phase of testing that have an improved accuracy over the ones used during the first round of testing. Overall the values are low and continued to be low after system operation.

Table 1. Pounds per MW-hr emissions of fuel cell gases.

Power Level	Analysis Date	Total Hydrocarbons	Carbon Monoxide	Carbon Dioxide	Oxygen	Oxides of Nitrogen (NO _x)	Oxides of Sulfur (SO _x)
100 kW	Feb 2000	0.042	0.080	0.226	0.303	0.112	Not Tested
100 kW	Oct 2002	0.003	<0.001	0.069	0.149	0.019	<0.002
200 kW	Feb 2000	0.007	<0.002	0.177	0.173	0.068	Not Tested
200 kW	Oct 2002	<0.001	0.006	0.160	0.167	0.024	<0.002

Grid Independent BT005B

Objective

The grid independent testing presented the power plant with combinations of both resistive and motor loads to simulate the power plant's ability to handle overloads. Presently, published specifications on the power plant list its steady-state capacity at 200 kW with overload capabilities up to 5 seconds at 240 kW. Documenting the actual overload possibilities provided increased flexibility for system planning for all PC25C users. The system response was monitored with

the FCTec Control and Data Acquisition System (CDAQ), and a Dranetz disturbance Analyzer.

Activity

For this test, the PC25C was set up for grid independent operation. A resistive load bank was used as the electrical loading means. All runs of this test began with a constant 200 kW resistive load. Overloads were applied as a step change, while monitoring power plant response. Overload tests started with the addition of a nominal overload. Further testing progressed in 5 kW overload steps until a steady state operating level was reached.

Starting at the same 200 kW power level, momentary overloads of varying sizes were applied for limited periods of time including 1, 2, 3, and 4 seconds. This tested the power plant's ability to maintain operation with short-term overloads.

Nominal loading levels and system response were recorded, along with specific output voltage, current, wattage, and transient voltage/current response, for each test.

Conclusion

This measurement of the fuel cells power plant's ability to manage overloads was performed both under the original Modification 2 testing as well as under the Modification 1 additional testing phase. All data and graphical information was transmitted to ERDC/CERL and UTC Fuel Cells on completion of the tests. The second operation of the overload capabilities of the PC25C allowed for a comparison of new power plant capabilities vs. a system approaching 22,000 hrs of use.

Figure 1 identifies the current impulse and corresponding voltage sag indicative of the overload conditions during the final test prior to a shutdown event. As the time duration for the overload is greater, the stress to the fuel cell system increases. The system capabilities at mid life decreased from the initial operation capabilities of 250 kW for 5 seconds and 220 kW for 10 seconds to 220 kW for 5 seconds at mid life.

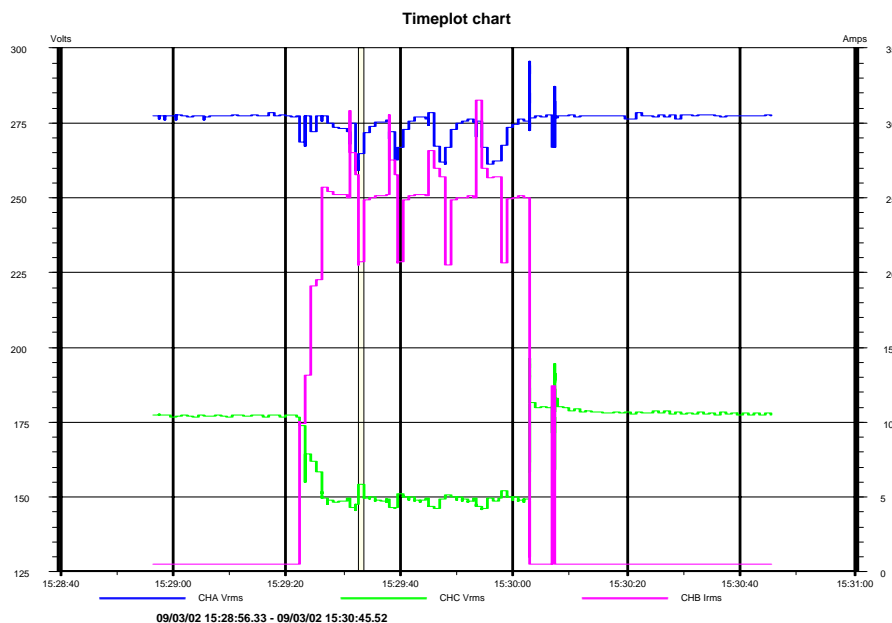


Figure 1. Overload time plot chart at 220 kW for 1, 2, 3, 4, and 5-second intervals.

Grid Independent BT005D

Objective

Obtain the necessary information to determine the power quality parameters of the PC25C while supplying varying electrical loads. Measurements used to indicate the relative quality of supplied electrical power include such items as voltage regulation (both steady state and transient), and wave shape quality (total harmonic distortion, THD).

Activity

For this test the power plant was operated in grid independent mode, and measurements taken at various steady state resistive and inductive (motor) load levels. Readings were achieved while cycling through a series of varying (transient) load levels. Additionally, a 20 hp pulse width modulated (PWM) drive and soft-start controllers were used as non-linear loads to determine their effect on the output voltage quality.

Measurements were taken using a Dranetz line analyzer, and a high-speed data acquisition system. Instantaneous voltage, current, and kW data were captured. The data were reported to ERDC/CERL and UTC Fuel Cells for comparison with unit specifications and IEEE standards.

Conclusion

Figure 2 is an example of the maximum voltage distortion of the PC25C power plant when exposed to the non-linear load of a 20 hp adjustable speed drive operating at 25 percent load to achieve the greatest distortion. The corresponding current distortion is identified in Figure 3. The 2.93 percent Voltage Total Harmonic Distortion (THD) from the PC25C power plant is well within the IEEE 519 requirements. Even at mid life of the fuel cell stack, the system responds extremely well to high levels of nonlinear loads.

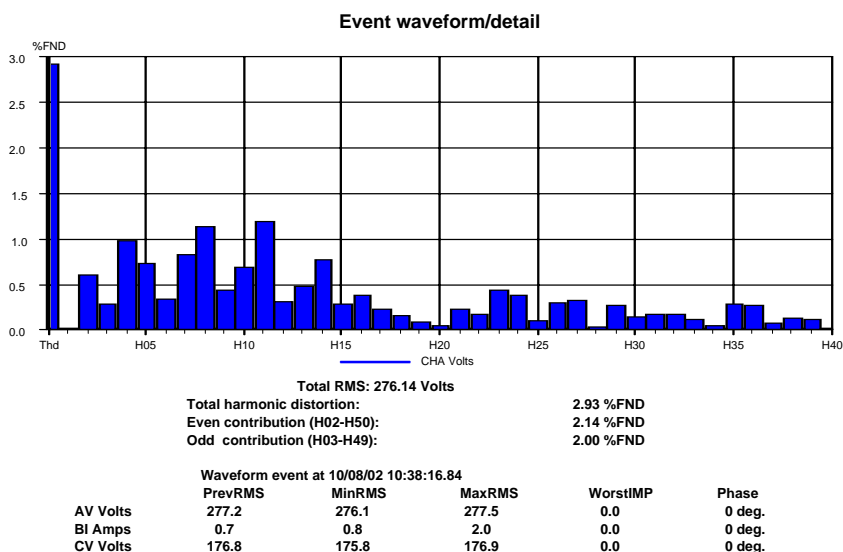


Figure 2. Maximum voltage distortion experienced under non-linear load.

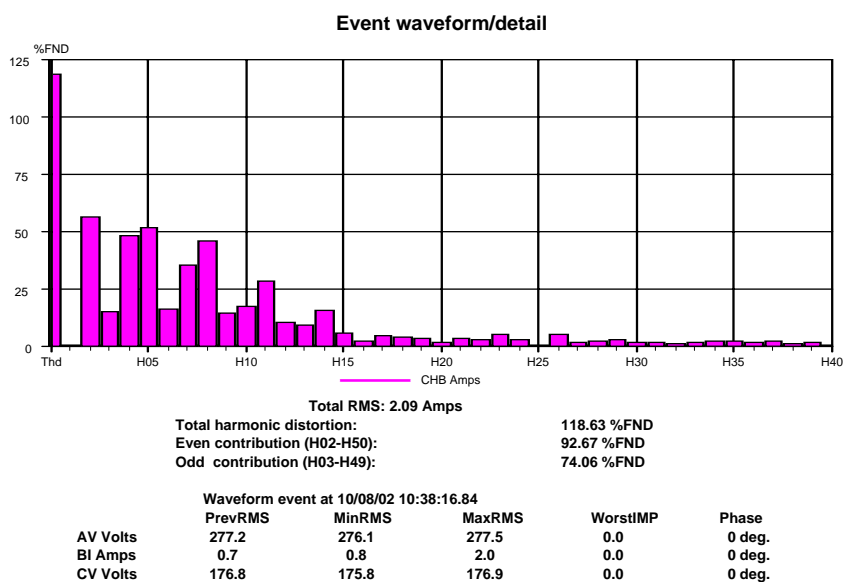


Figure 3. Maximum current distortion under nonlinear load.

Modification 2 Activities

Pre Test Hydrodesulfurizer (HDS) BT001A

Objective

This testing investigated the operation of the hydrodesulfurizer (HDS) bed in the integrated low temperature shift converter (ILS). This task is to define possible improvements to the hydrodesulfurizer catalyst bed configuration that will improve the “sulfur slip” presently experienced in the PC25C fleet. “Sulfur slip” causes poisoning of the reformer catalyst. Reduction in the reliability and life of the power plant is the outcome. Testing included catalyst bed heater locations, method of heater control, temperature sensor location, and revised temperature set points. A schematic of the heater locations and the standard thermocouple positions is included with the test plan information in Appendix B.

Activity

Temperature data from a specially instrumented hydrodesulfurizer (HDS) system identified the optimum temperature profile from top to bottom of the catalyst bed. Maximum and minimum design temperatures in the bed were being exceeded using a typical on/off control scheme. It is theorized that the excessive temperature gradients in the HDS catalyst bed, induced by the placement and cycling of the HTR002 heaters, contributed to the “sulfur slip.”

To test various options for temperature profile improvement in the HDS, an array of 33 additional thermocouples and three additional heaters, for a total of six, were added to the HDS bed in accordance with drawings and instructions provided by UTC Fuel Cells. UTC Fuel Cells also provided a formalized test plan that included operating the power plant at two power levels, 80 kW and 200 kW, for evaluation of heater control while using three of the six available heaters and one of several thermocouples for temperature control during the various test configurations. Test configurations were selected that would lead to a definition of a heater and control thermocouple design that could be implemented in field power plants. The test plan also included provisions for sampling the HDS exit gas for sulfur compounds.

Testing of the HDS bed for sulfur removal was conducted in three phases. Phase I included testing of the desulfurization unit in normal configuration, Phase II used various heater configurations, and Phase III used an electronic process heater control to provide a very narrow controlled temperature. To prepare for the testing additional thermocouples and heaters were added to the HDS bed.

The heaters provided a means for varying the heated zones inside the HDS while the thermocouples provided for the measurement of internal temperatures across the HDS bed. The new thermocouple information was included within the data acquisition system to allow reporting and plotting of the values.

Phase I testing was performed by collecting samples of natural gas and processed gases at access ports AP001, reformer inlet and AP003, reformer outlet in a batch method, using Suma canisters. The canisters were sent to AirToxics in California for sulfur compound speciation and measurement using American Society for Testing and Materials (ASTM) Method 5504.

A series of tests were conducted to document the temperature profile in the HDS bed using the bill-of-material heaters, control thermocouple, and on/off heater control. Temperature data were collected at two power levels, 80 kW and 200 kW. With this heater and control configuration, a maximum temperature range within the bed of 385 °F from the hottest to coldest thermocouple was observed at 200 kW with the heaters on and at the top of the temperature cycle. It would reduce to 150 °F at the bottom of the cycle. Per UTC Fuel cells, this large temperature range exceeds the optimum range for full use of the hydrodesulfurizer catalyst and sulfur absorbent. In addition, the top-to-bottom temperature profile within the bed showed that the coldest zone was at the top of the bed where the natural gas enters and the hottest zone was near the bottom. This is just the opposite of the desired profile. A plot of this temperature data, provided by UTC Fuel Cells, is in Figure 4.

UTC Fuel Cells suggested that the top-to-bottom temperature profile identified that it was desirable to revise the heater placement on the HDS vessel to add more heat to top of the bed instead of the bottom as in the original configuration. Three new heater configurations were tested to accomplish this, using heater bands near the top and above the bed for inlet gas heating. This segment of testing used a control thermocouple location higher in the bed.

Per UTC Fuel Cells, the first configuration tested gave unacceptable results with excessively high local bed temperatures. The next configuration successfully increased the temperature at the top of the bed as compared to the baseline data but the temperature range within the bed, now 463 °F, was worse than the baseline configuration. The identification of a third and more desirable configuration for the heater bands was accomplished. To retain the improved top-to-bottom of temperature profile but reduce the excessive temperature range within the bed, two heaters near the top of the bed and one above the bed on the vessel wall gave the best results.

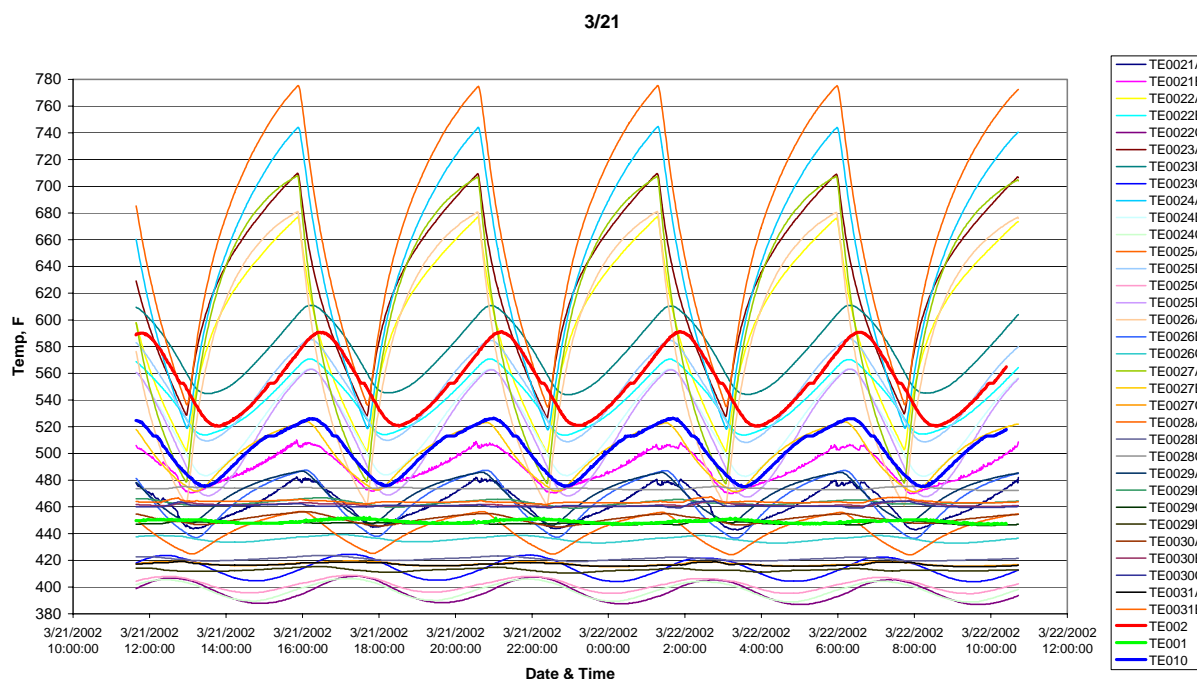


Figure 4. UTC fuel cells HDS temperature cycling, BOM configuration.

CTC relocated and repositioned the control thermocouple to reduce the magnitude of the temperature swings within the catalyst bed as the heaters cycle. *CTC* moved the control thermocouple closer to the vessel wall and relocated it to a higher elevation, near the newly located heaters.

These modifications dramatically improved the temperature control. UTC Fuel Cells were pleased with the outcome whereby the period of the on/off heater cycle was reduced from 3¼ hrs to 20 minutes and the maximum temperature fluctuation at any local area in the bed was reduced from 200 °F to 26 °F. In addition, the worst case temperature spread within the bed at the top of the temperature cycle was reduced from 385 °F to 287 °F. UTC Fuel Cells graphed the temperature profile in the bed under this configuration (Figure 5).

CTC sampled the hydrodesulfurizer exit gas into batch containments and delivered them to the outside lab for sulfur analysis. Using a lower detection level that ranged from 7.5 to 10 ppbV, no sulfur was detected.

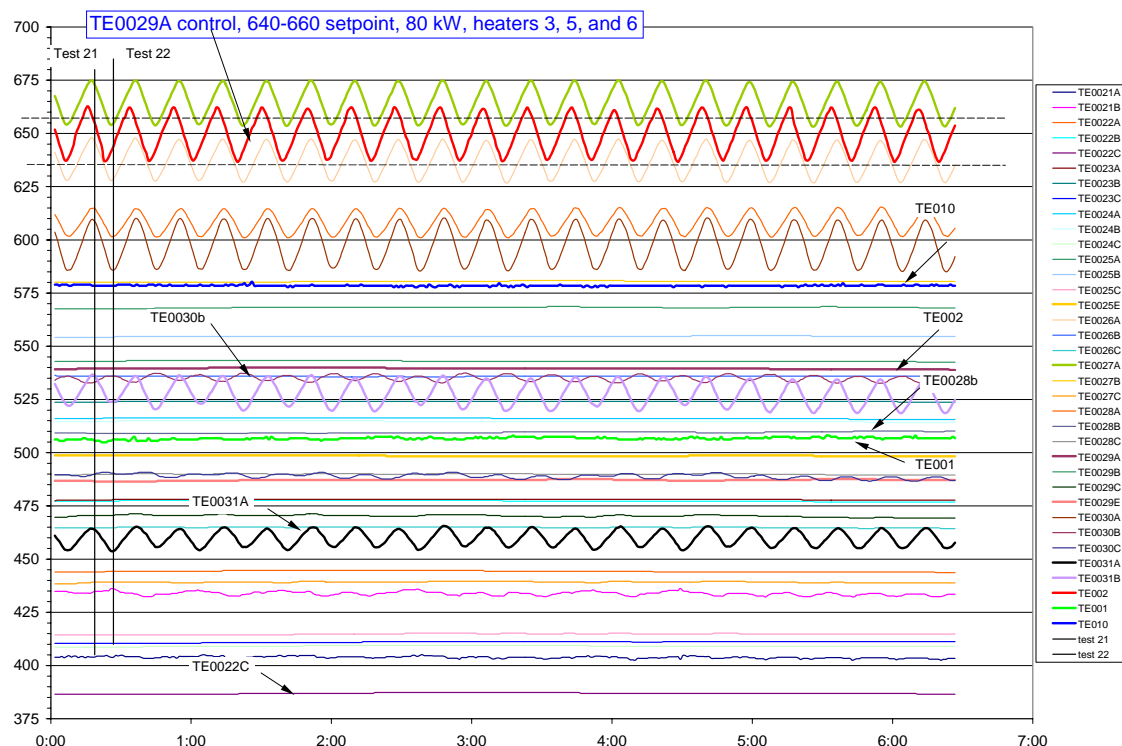


Figure 5. Improved HDS temperature profile, relocated heaters and control TC.

Before Phase II testing began, a heated sample line and pump were added to transfer the gas sample from port AP003, reformer outlet, to a Gas Chromatographic system (GC) upgraded by OI Analytical with a Pulsed Flame Photometric Detector (PFPD). The PFPD allows for the detection and measurement of low levels of sulfur in sample compounds. The gas chromatograph analysis provided a measurement of the effects of varying the heating profile, thermal zones, and operational parameters on sulfur removal. Using the direct capture and measure method provided by the specialized gas chromatograph, accurate immediate measurements of the sulfur concentrations were possible. Comparisons of the canister and gas chromatograph methods were provided to UTC Fuel Cells. The gas chromatograph method allowed for an improvement in sulfur detection in all cases.

Phase II testing included the addition of an electronic system for temperature control. CTC installed this system to allow finite control of the monitored temperature. On implementation, the control temperatures no longer had an on/off dead band. The Phase II testing varied the heater temperatures, changed the location of heated zones, and measured the sulfur species using the gas chromatograph. Optimum operating parameters were identified using these experimental conditions.

CTC operated the power plant at 80 kW and 200 kW using the electronic temperature controller with the heaters and the control thermocouple located in the bill of material, original locations. The results were poor, with the temperature at the control thermocouple location cycling plus or minus 20 °F about the set-point, and the cycle period was about 2½ hrs.

The HDS bed temperature control thermocouple was relocated near the vessel wall at the preferred location determined during earlier testing. Testing of three heater configurations was conducted with a set point temperature of 640 °F and with the power plant operating at 80 kW and 200 kW. Based on the HDS bed temperature data, a heater configuration to achieve the best temperature profile was identified and it was the same configuration that gave the best results during Phase 1 testing when the on/off heater control was used.

The gas chromatograph sampled the gas at the HDS exit to identify trace amounts of certain sulfur compounds. Detection of the individual sulfur compounds was above a 2 ppbV level with none detected at levels greater than 8 ppbV. The highest total sulfur level detected (the sum of the individual compound levels) was 16 ppbV. The highest sulfur levels were detected shortly after making load change transients, and the peaks seemed to be present for only a few minutes. These sulfur levels are shown in the UTC Fuel Cells Figure 3 at various test conditions.

With a technique established for quantifying very low sulfur levels by gas chromatography, sulfur analyses were repeated with the baseline HDS heater configuration and with the original on/off heater cycling. The highest total sulfur level detected was 8 ppbV and the sulfur compound most prevalent was carbonyl sulfide, at about 4 to 5 ppbV.

Sulfur was infrequently found by the sample canister method used in Phase I, and levels were very low when the analysis was performed using the gas chromatograph method in Phase II. The hydrodesulfurizer catalyst activity and overall HDS performance appeared to be acceptable throughout most of the Phase II testing. This is attributed to the relatively clean natural gas in the Johnstown, PA area. This gas contains a moderate amount of sulfur compounds as odorants that are easily reacted in the HDS. In other parts of the country, the natural gas contains high levels of sulfur compounds, some of which may pass through the HDS with the possibility of poisoning the reformer catalyst.

As part of this testing, the control constants for the programming of the electronic heater controller were determined. Satisfactory control constants to achieve smooth temperature control were selected. It was also determined that

the heater control did not adversely affect the power plant controller. The stability of temperature control with the electronic controller is also indicated in UTC Fuel Cells Figure 6.

Phase III testing attempted to accomplish similar results to the electronic temperature control with the use of the balance of plant on/off controller. This was accomplished by positioning a thermocouple in what UTC Fuel Cells determined would be the optimum location and using the balance of plant on/off controller. This method would provide for a less expensive retrofit if successful.

During Phase III, temperature control was evaluated using the bill-of-material TE010 location but with the thermocouple inserted into the bed only $\frac{1}{4}$ in. This location is about 12 in. lower in the bed than the control TC used in Phase II but 12 in. higher than the original control thermocouple TE002. Temperature control was evaluated at various power levels and set point temperatures to match the bed temperatures achieved in Phase II. It was confirmed that the TE010 port could be satisfactorily used for temperature control as necessary using a set point temperature of 605 °F.

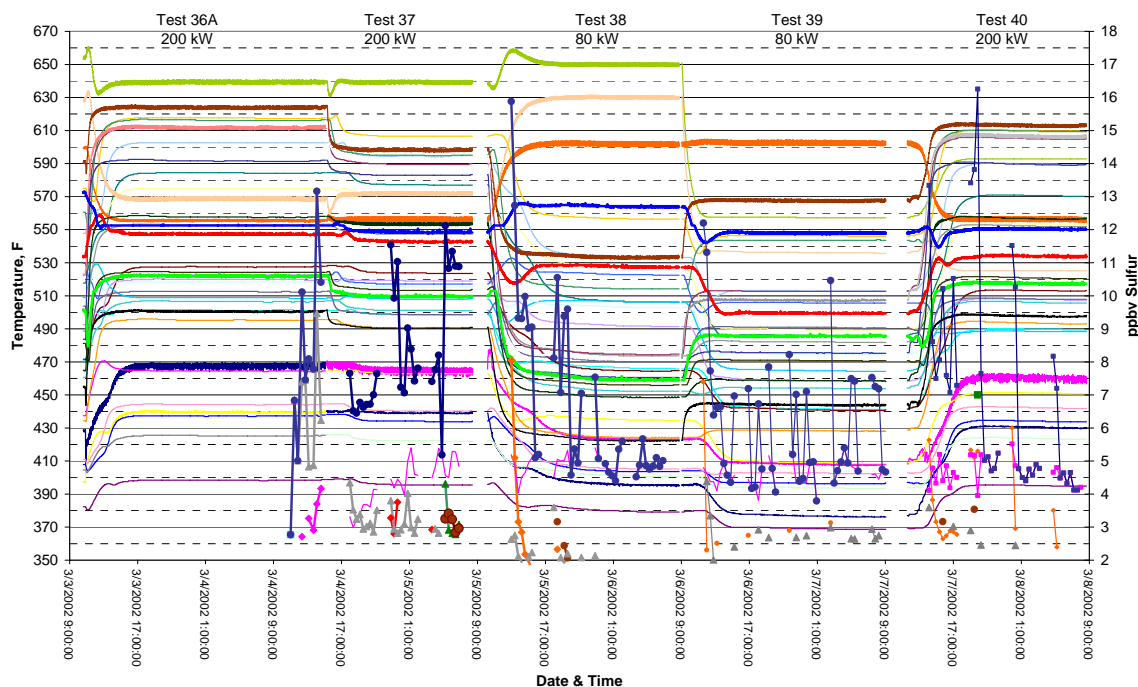


Figure 6. HDS bed temperature with electronic control and sulfur analysis.

Conclusion

In Phase I testing, HDS heater and control thermocouple locations were identified that greatly improved the temperature profile in the HDS catalyst bed. The two key changes were: (1) locating the control thermocouple close to the vessel wall, which reduced the heater cycle time, and (2) repositioning the heater bands higher on the vessel wall to produce a more desirable temperature profile, with the hotter zone on top at the gas inlet where the hydrodesulfurizer catalyst will have the greatest activity.

In Phase II testing, a better temperature control, without heater cycling, was obtained by using an electronic, Proportional, Integral, and Derivative (PID) heater controller. In addition to eliminating cycling, the electronic controller will extend heater life by minimizing extreme temperature differentials and thermal fatigue failure of the heater elements.

In Phase III, a practical approach for implementing the new heater control scheme in the PC25C fleet was developed. On dual-fuel ILS units, like the system at the FCTec, an existing thermocouple port on the HDS vessel was used without incurring a high expense or excessive power plant down time for extensive HDS modifications.

The final outcome of the testing resulted in the use of an existing thermocouple location TE 010, the relocation of the thermocouple to a position near the outside wall, and the use of a temperature set point of 605 °F with the electronic temperature control system. This configuration used the new HDS heater locations at position 3, 5, and 6. Temperatures at 80 kW and 200 kW power levels were satisfactory, varying between 486 °F and 592 °F. This setup will provide the best overall sulfur removal with a low implementation cost.

Reference Natural Gas Testing BT001B

Objective

The Reference Natural Gas (RNG) testing established a baseline of power plant operation in a standard configuration at the beginning of life for use in comparison to subsequent operation over the power plant life and different plant configurations. This test has been repeated at different stages of life to document power plant aging and evaluate the need to re-tune the power plant to optimize performance. This testing assessed the long term effects of the operation of the fuel cell system on the composition of gases produced at various locations through out the system, at various power settings.

Activity

For all test runs, the power plant operated on utility natural gas in the grid connect mode with no customer heat recovery. The tests were established and designated by net power output levels to include idle mode, 50 kW, 80 kW, 100 kW, 125 kW, 150 kW, 175 kW, and 200 kW. The power plant systems were set up and configured for normal operation per the UTC Fuel Cells PC25C operations manual. Each condition was held a minimum of 3 hrs to ensure a stabilized load condition. Data collected included the power plant RADAR dataset and the CTC provided CDAQ data as well as gas analysis composition via gas chromatograph. CTC and UTC Fuel Cells reviewed all data captured for each power level following the completion of this test series.

Because of some gas chromatograph issues noted during evaluation of the initial test data, portions of the test (Idle, 50 kW, 100 kW and 200 kW) were repeated in early May 2000 to confirm these earlier results.

After operating for 15,000 load hours, this test was repeated in January 2002 to determine the need for a re-trim of the reformer temperature schedule to maintain optimum power plant performance.

All pertinent measured, monitored, and computed parameters from the FCTec data acquisition system and the PC25C's existing data acquisition system were recorded and stored for each test run. Specific data samples captured for this test series included:

- Gas analysis (H_2 , CO_2 , O_2 , N_2 , CO , and CH_4) of the Reformer Process Exit
- Gas analysis (H_2 , CO_2 , O_2 , N_2 , CO , and CH_4) of the Anode Inlet and Anode Outlet
- Gas analysis (H_2 , CO_2 , O_2 , N_2 , CO , and CH_4) of the Burner Exhaust
- Gas analysis (H_2 , CO_2 , O_2 , N_2 , CO , and CH_4) of the Cathode Exit
- Cell Stack Assembly (CSA) cross pressure (anode inlet to cathode inlet)
- Glycol inlet and exit temperatures of cooling module
- Ambient temperature of cooling module area
- Exiting air temperature from cooling module fans
- Cooling module on/off status
- Feed water on/off status.

Gas analysis was performed using a Perkin Elmer auto-system gas chromatograph equipped with a light gas analysis kit. This system uses thermal conductivity detection and a gas-sampling loop to introduce the sample onto a chromatography column. The column consists of a Haye's separation column before the sample enters a molecular sieve column. After injection onto the column, carrier

gas (8.5 percent Hydrogen in Helium) moves Hydrogen in the sample through both columns to the detector. A valve closes to trap Oxygen, Nitrogen, Carbon Monoxide, and methane on the molecular sieve column while carbon dioxide and other gases (ethane, propane, carbon disulfide, etc.) pass through the Haye's column to the detector. The valve then returns to its original position to move the remaining gases to the detector.

Teflon tubing was used to collect gas samples. A dry sample was introduced to the gas chromatograph by using an impinger to remove bulk water. The sample then passed through a TESTO air-cooled gas drier and finally an impinger filled with desiccant to remove traces of moisture. The sample was drawn through the sample loop using a gas sampling pump.

Calibration of the instrument for the analysis of oxygen, carbon monoxide and carbon dioxide was accomplished using certified compressed gas standards. Calibration for Nitrogen and Hydrogen was performed using pure (99.999 percent) compressed gas standards. A dry gas meter was used to prepare compositions of 20% N₂/80% H₂, 40% N₂/60% H₂, 60% N₂/40% H₂, and 80% N₂/20% H₂ in 1.6 cu ft Tedlar bags. Air was used to confirm Oxygen and Nitrogen calibration curves. Finally, methane calibration was performed by injecting known volumes of pure methane gas using gas-tight syringes into Nitrogen filled Tedlar bags. These calibration methods are documented in the *CTC* ISO standards.

As a comparison tool, an Anarad testing system supplied by UTC Fuel Cells, collected gas composition data at various power levels. These data were compared to the analytical information received using gas chromatography to verify the results. A hand-held gas analyzer, TESTO 350, was also used to collect Oxygen concentration data on the cathode exit and burner exhaust ports. A spreadsheet form included all data along with the input collected using computerized data acquisition software. This information was transmitted to UTC Fuel Cells by the *FCtec* File Transfer Protocol (FTP) location.

Conclusion

The test power plant, SN9194, located within the *CTC* Environmental Technology Facility (ETF) began operation in November 1999. When the power plant was not engaged in specific testing, it generally operated at 200 kW during the day and at 80 kW during the overnight and weekend periods.

With about 600 load hours on the power plant, the reference Natural Gas testing began in mid January 2000. The gas composition at the reformer process exit, the anode inlet and the anode exit were measured via the *CTC* GC at the power

levels as outlined in the test information. The initial gas analysis results using the gas chromatograph were invalid because the carrier gas was tainted. After resolving the issue with the gas chromatograph the gas composition was re-analyzed in May 2000 with improved results. Table 2 lists the gas analysis for idle, 50 kW, 100 kW, and rated power 200 kW. UTC Fuel Cells provided the fuel conversion and hydrogen use calculations based on the measured composition levels reflected. Testing resulted in a lower than expected steam flow above idle.

Table 2. Gas analysis results, gas chromatograph (May 2000).

Reformer Process Exit

Power	H ₂	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	psi
Idle	78.4	0.2	10.1	11.3	0.0	0.0	0.991	0.472
50 kW	77.8	0.8	9.5	11.9	0.0	0.0	0.964	0.444
100 kW	77.6	0.8	9.4	12.2	0.0	0.0	0.964	0.435
200 kW	77.2	0.9	9.2	12.7	0.0	0.0	0.961	0.420

Anode Inlet

Power	H ₂	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	psi
Idle	81.8	0.2	17.8	0.2	0.0	0.0	0.989	0.989
50 kW	81.0	0.7	18.0	0.3	0.0	0.0	0.963	0.984
100 kW	81.2	0.7	17.9	0.2	0.0	0.0	0.963	0.989
200 kW	80.5	0.8	17.7	1.0	0.0	0.0	0.959	0.947

Anode Exit

Power	H ₂	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	psi	UH ₂
Idle	49.6	0.5	49.6	0.3	0.0	0.0	0.990	0.994	0.781
50 kW	49.6	1.7	48.1	0.6	0.0	0.0	0.966	0.988	0.769
100 kW	50.9	1.6	47.0	0.5	0.0	0.0	0.967	0.989	0.760
200 kW	50.1	2.1	45.6	2.2	0.0	0.0	0.958	0.954	0.757

Theta: Fuel Conversion

UH₂: Hydrogen Use

As a result, an indirect steam flow measurement was made via a water tank (TNK450) draw down procedure. This procedure restricts the water tank return flows (TMS blow down and condensate) from the water tank. With the drop in TNK450 level, an estimate of the steam flow was to be made. UTC Fuel Cells determined that by the results of this testing at 100 kW and 200 kW the process steam schedule was deficient by approximately 10 percent. The steam schedule was subsequently increased and the gas composition re-evaluated at 100 kW, 150 kW and 200 kW power levels. Table 3 lists the results of a representative revised steam schedule's gas analysis.

Table 3. Gas analysis results, gas chromatograph (August 2000).**Reformer Process Exit**

Power	H ₂	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	psi
100 kW	78.3	1.2	9.9	10.3	0.3	0.0	0.944	0.490
150 kW	77.7	1.1	10.4	10.5	0.3	0.0	0.950	0.498
200 kW	78.5	0.1*	9.3	11.8	0.3	0.0	0.995	0.441

Anode Inlet

Power	H ₂	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	psi
100 kW	80.4	1.1	18.0	0.1	0.3	0.0	0.942	0.944
150 kW	80.5	1.0	17.9	0.3	0.3	0.0	0.948	0.983
200 kW	80.7	0.7	17.7	0.7	0.2	0.0	0.963	0.962

Anode Exit

Power	H ₂	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	psi	UH ₂
100 kW	48.5	2.9	47.4	0.5	0.8	0.0	0.943	0.990	0.770
150 kW	49.3	2.5	46.5	0.8	0.9	0.0	0.950	0.983	0.764
200 kW	50.4	1.9	45.2	1.9	0.6	0.0	0.961	0.960	0.757

*based on fuel conversion at anode inlet and exit suspect CH₄ should be 0.8%

The power plant was shut down in December 2001 to repair a slipped manifold seal in the cell stack. CTC performed a gas analysis using the UTC Fuel Cells Anarad, a three-channel non-dispersive infrared (NDIR) gas analyzer, after the system was restarted. Table 4 lists the gas analysis after the repair and restart.

Table 4. Gas analysis results, field anarad (December 2001).**Reformer Process Exit**

Power	H ₂ (by diff)	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	Psi
80 kW	77.4	1.0	10.8	10.8	—	—	0.956	0.500
200 kW	77.7	0.9	10.1	11.3	—	—	0.960	0.472

Anode Inlet

Power	H ₂ (by diff)	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	Psi
80 kW	79.7	0.9	18.8	0.6	—	—	0.956	0.969
200 kW	79.6	0.9	17.6	1.9	—	—	0.956	0.903

Anode Exit

Power	H ₂ (by diff)	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	psi	UH ₂
80 kW	46.9	2.3	49.7	1.1	—	—	0.957	0.978	0.775
200 kW	49.1	2.2	44.3	4.4	—	—	0.957	0.910	0.753

UTC Fuel Cells response to the gas tables indicated that that the fuel conversion and hydrogen use were as expected at 0.96 and 0.76 respectively. The CO level exiting the Low Temperature Shift Catalyst (LTSC) bed to the anode inlet had increased to 1.9 percent, per UTC Fuel Cells the typical level is 0.7 to 1.0 percent. High CO will adversely impact cell performance, particularly the end cells at the top and bottom of the CSA, because these cells are colder. To reduce the CO level, the steam schedule was further increased by 10 percent.

The baseline gas analysis taken in January 2002, was performed with both the CTC GC and the UTC Fuel Cells NDIR system. Table 5 is the gas chromatograph data. Table 6 is the NDIR data. The CO level at the anode inlet had reduced to 1.3 percent as indicated in the NDIR data. Because of equilibrium, any further increase in steam flow results in diminishing returns. With that, no additional changes were made to the steam schedule.

Table 5. Gas analysis results, gas chromatograph (January 2002).

Reformer Process Exit

Power	H ₂	CH ₄	CO ₂	CO*	N ₂	O ₂	Theta	psi
Idle	74.5	0.2	18*	7.3	0.0	0.0	0.992	0.711
50 kW	80.2	1.0	11.2	7.6	0.0	0.0	0.949	0.596
80 kW	78.4	1.1	12.2	8.3	0.0	0.0	0.949	0.595
100 kW	78.6	1.2	12.0	8.2	0.0	0.0	0.944	0.594
125 kW	79.4	1.0	12.2	7.4	0.0	0.0	0.951	0.622
150 kW	80.0	1.1	11.4	7.5	0.0	0.0	0.945	0.603
175 kW	79.2	1.2	11.1	8.5	0.0	0.0	0.942	0.566
200 kW	79.2	0.9	10.9	9.0	0.0	0.0	0.957	0.548
200 kW	83.9	0.7	8.4*	7.0	0.0	0.0	0.957	0.545

Anode Inlet

Power	H ₂	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	psi
Idle	85.2	0.1	14.5*	0.2	0.0	0.0	0.993	0.986
50 kW	78.8	0.9	19.8	0.5	0.0	0.0	0.958	0.975
80 kW	78.4	1.1	20.3	0.2	0.0	0.0	0.949	0.990
100 kW	79.5	1.2	16.7	2.6*	0.0	0.0	0.941	0.865
125 kW	79.9	1.0	18.0	1.1	0.0	0.0	0.950	0.942
150 kW	79.1	1.2	18.6	1.1	0.0	0.0	0.943	0.944
175 kW	77.9	1.2	20.3	0.6	0.0	0.0	0.946	0.971
200 kW	74.8	0.7	23.4*	1.1	0.0	0.0	0.972	0.955
200 kW	83.3	0.7	15.3*	0.7	0.0	0.0	0.958	0.956

Anode Exit

Power	H ₂	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	psi	UH ₂
Idle	61.4	0.4	37.8*	0.4	0.0	0.0	0.990	0.990	0.724
50 kW	46.8	2.3	50.5	0.4	0.0	0.0	0.957	0.992	0.763
80 kW	43.0	2.5	54.0	0.5	0.0	0.0	0.956	0.991	0.792
100 kW	63.3	2.3	34.2*	0.2	0.0	0.0	0.937	0.994	0.555
125 kW	50.4	2.3	46.8	0.5	0.0	0.0	0.954	0.989	0.744
150 kW	46.6	3.0	49.4	1.0	0.0	0.0	0.944	0.980	0.769
175 kW	57.9	2.3	38.6*	1.2	0.0	0.0	0.945	0.970	0.610
200 kW	40.1	2.2	51.9	5.8*	0.0	0.0	0.963	0.899	0.774
200 kW	58.0	1.7	38.6*	1.7	0.0	0.0	0.960	0.958	0.723

*error in readings

Table 6. Gas analysis results, field anarad (January 2002).

Reformer Process Exit

Power	H ₂ (by diff)	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	psi
Idle	77.4	0.2	11.4	11.0	—	—	0.991	0.509
50 kW	76.1	1.0	12.5	10.4	—	—	0.958	0.546
80 kW	76.3	0.7	13.2	9.8	—	—	0.970	0.574
100 kW	76.6	1.0	12.2	10.2	—	—	0.957	0.545
125 kW	76.8	0.9	12.6	9.7	—	—	0.961	0.565
150 kW	67.8	1.0	11.8	19.4*	—	—	0.969	0.378
175 kW	77.1	0.9	11.4	10.6	—	—	0.961	0.518
200 kW	76.5	0.7	11.3	11.5	—	—	0.970	0.496
200 kW	76.5	0.7	11.4	11.4	—	—	0.970	0.500

Anode Inlet

Power	H ₂ (by diff)	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	psi
Idle	79.6	0.2	19.8	0.4	—	—	0.990	0.980
50 kW	79.2	0.9	19.5	0.4	—	—	0.957	0.980
80 kW	78.8	1.2	19.5	0.5	—	—	0.943	0.975
100 kW	78.8	1.0	19.7	0.5	—	—	0.953	0.975
125 kW	78.5	0.9	20.0	0.6	—	—	0.958	0.971
150 kW	79.0	0.9	19.4	0.7	—	—	0.957	0.965
175 kW	79.3	0.9	18.8	1.0	—	—	0.957	0.949
200 kW	79.1	0.6	18.9	1.4	—	—	0.971	0.931
200 kW	79.0	0.7	19.0	1.3	—	—	0.967	0.936

Anode Exit

Power	H ₂ (by diff)	CH ₄	CO ₂	CO	N ₂	O ₂	Theta	psi	UH ₂
Idle	51.7	0.5	47.2	0.6	—	—	0.990	0.987	0.726
50 kW	45.7	2.3	51.1	0.9	—	—	0.958	0.983	0.779
80 kW	48.8	1.8	48.5	0.9	—	—	0.965	0.982	0.744
100 kW	47.6	2.5	49.0	0.9	—	—	0.952	0.982	0.756
125 kW	47.0	2.3	49.6	1.1	—	—	0.957	0.978	0.757
150 kW	46.8	2.7	48.8	1.7	—	—	0.949	0.966	0.766
175 kW	46.9	2.5	48.1	2.5	—	—	0.953	0.951	0.769
200 kW	48.1	1.8	46.8	3.3	—	—	0.965	0.934	0.755
200 kW	46.6	1.8	48.1	3.5	—	—	0.966	0.932	0.768

* error in readings

The reformer, as defined by the gas analysis, shows no deterioration since the initial operation of the power plant. Per UTC Fuel Cells, this trend is typical of PC25 fleet experience. The low temperature shift catalyst shows some indications of diminished capability. UTC Fuel Cells claims that this is not unusual in the PC25 fleet although the change in 9194 appears to be higher than expected. Periodic gas analysis should be performed to continue the evaluation of the LTSC performance over time.

The fuel cell stack within the system as tested has accumulated 22,000 load hours as of 4-01-2003. Per UTC Fuel Cells, stack performance throughout the operation has been within the expected band for a 32 substack cell stack assembly. Figure 7, supplied by UTC Fuel Cells, identifies the estimated total system voltage with no shutdowns as compared with 6 to 8 shutdowns per year.

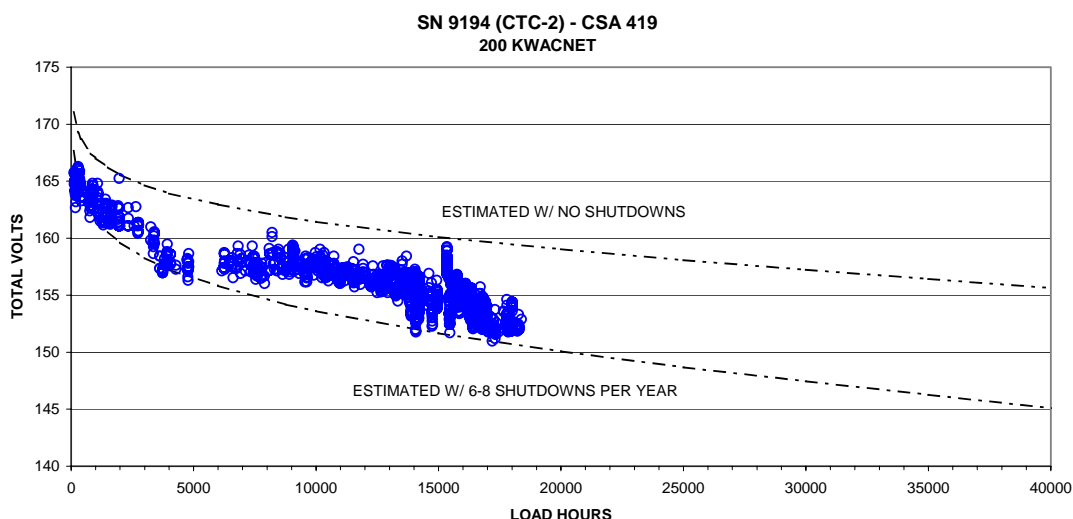


Figure 7. Fuel Cell Power Plant 9194 stack voltages at 200 kW power output.

Power Plant 9194, substack voltage profile, shown in Figure 8, identifies substack voltages over the operation of the system. As a whole, there are no significant issues with the voltage profile. The higher than expected CO concentrations through the stack may account for the slight drop at the end sub modules. The trend of the voltage profile looks essentially the same at 18000 hours as it did at 2000 hours.

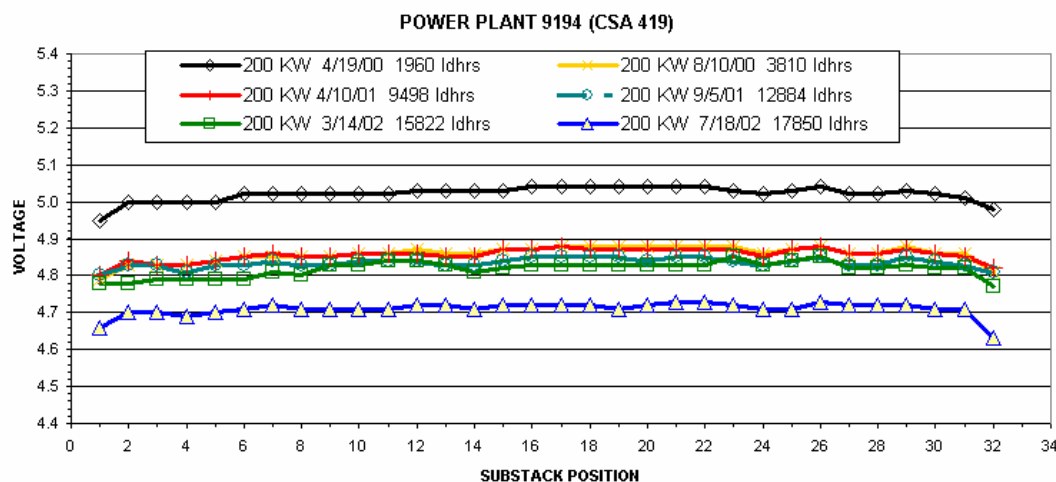


Figure 8. Fuel Cell Power Plant 9194 sub-stack voltage profile.

An outdoor fan cooled condenser maintains the appropriate fuel cell system temperature for the system requirements. This cooling system is comprised of four low speed, low noise fan motors that operate on a temperature signal. Noise recordings were documented using a digital CEL-328 sound meter at five positions around the cooling module at a distance of 30 ft away. The noise level produced by the cooling module fans was no more than 57 decibels, which is less than normal voice conversation level (70 dB). The start up noise was only slightly higher at 61 dB. The background noise measured at the same points was 45 dB. The new cooling module was significantly quieter than the past systems and is lower than normal voice conversation level that is typically at 70 dB.

Heat Recovery BT003

Objective

The purpose of the PC25C Fuel Cell Power Plant heat recovery testing was to document the available heat recovery capability from the low and high-grade heat recovery customer interfaces of the PC25C. Additionally, the customer side pressure drop through each heat recovery heat exchanger was characterized. This testing assisted in the knowledge source for future PC25C designs using the combined heat and power application. Obtaining the proper heat recovery possible at varying power levels is imperative to design applications where the recovered heat is being used to replace other thermal supplies. This information was used during the installation of a multi-system installation at the U.S. Postal Service facility in Anchorage, AK.

Activity

Additional heat recovery testing was initiated during May of 2002. At the time of this testing the power plant had operated for approximately 17,000 load hours. CTC Installed a new low range flow meter in the thermal load test stand to improve the system accuracy below 25 gpm. Based on the past review of the test results it was concluded that the high range flow meter was not sufficiently accurate over the entire flow range of 8 to 130 gpm. The low range flow meter provided results more accurate results to define the actual thermal output of the system.

High Grade Heat Exchanger Testing

This phase of thermal testing used three different customer return temperatures and three flow rates with the two flow meters available (Table 7).

Table 7. High grade heat exchanger test conditions.

High Grade Heat Exchanger Testing (Hex 490) @ 200 kW				
Customer Side Return Temp (°F)	Customer Side Flow Rate (gpm)			
	Low flow meter		High flow meter	
150	15	25	25	50
200	15	25	25	50
250	15	25	25	50

The test conditions allowed the flows to overlap at 25 gpm to compare the high flow and low flow meter information. Figure 9 shows the results of the high-grade heat exchanger testing as supplied by UTC Fuel Cells.

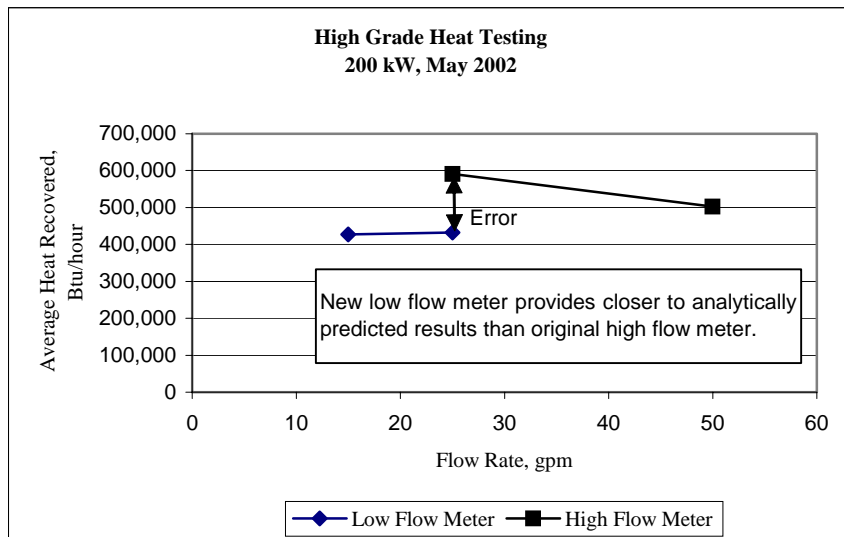


Figure 9. High-grade heat recovery, low vs. high range flow meter.

Comparison

The available heat per design should be in the range of 300,000 Btu/hr to 350,000 Btu/hr during the initial operation of a 32-substack PC25C power plant at beginning of life. As the power plant ages, additional high-grade heat is available because of the increasing inefficiencies of the system. The approximate 425,000 Btu/hour of heat recorded by the low-flow meter at 25 gpm agrees with past reported levels of high-grade heat. The near 600,000 Btu/hour result recorded by the high-flow meter at 25 gpm was inaccurate because of the use at the very low extremes of the meters capabilities.

Low Grade Heat Recovery

This phase of thermal testing used three different customer return temperatures and three flow rates with the two flow meters available. This is demonstrated in Table 8.

Table 8. Low grade heat exchanger test conditions.

Low Grade Heat Exchanger Testing (Hex 880) @ 200 kW				
Customer Side Return Temp (°F)	Customer Side Flow Rate (gpm)			
	Low Flow Meter		High Flow Meter	
80	10	25	25	50
120	10	25	25	50
160	10	25	25	50

The results of the new low-grade heat exchanger testing are shown in Figure 10 for the 25 gpm customer flow case. Heat recovery is plotted versus customer water temperature into the fuel cell low-grade heat exchanger. As with the high-grade test results, the low range flow meter provided results with increased accuracy.

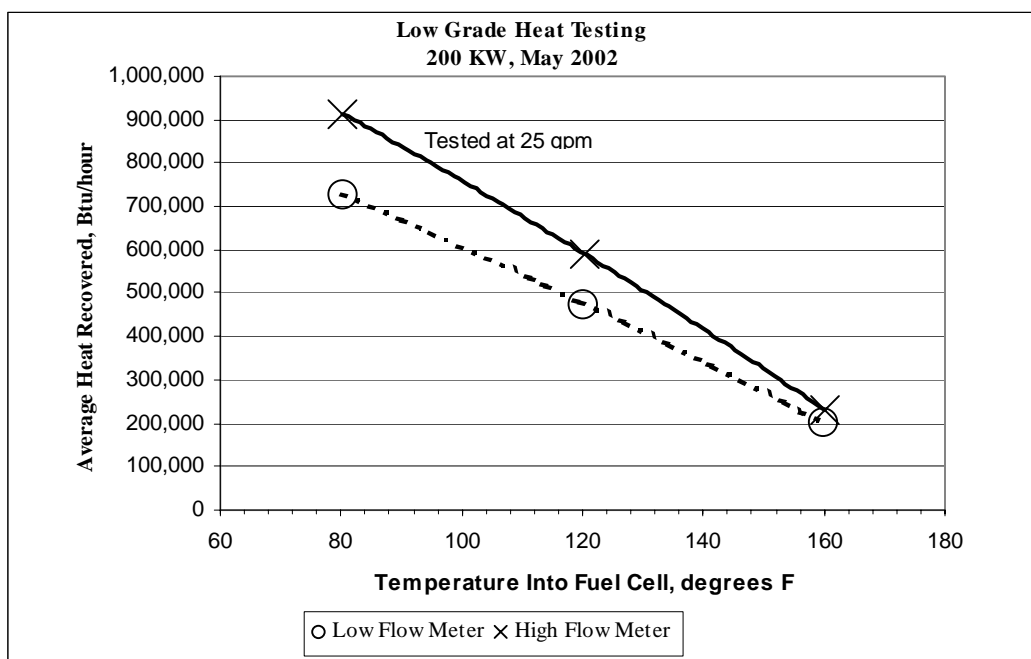


Figure 10. Low-grade heat recovery, flow meter comparison (@ 25 gpm).

Conclusion

As a result of the *CTC* testing the heat recovery characteristics have been updated in the latest edition of the PC25 Fuel Cell Power Plant Manual. All data from the various flows are cataloged in the BT003, Thermal Recovery, data archive. The high flow meter accuracy at 50 gpm is appropriate and confirms the available heat recovery from the system.

At initial use of a PC25C power plant, the amount of total recoverable heat is predicted to be approximately 725,000 Btu/hour with the high-grade heat contribution of approximately 275,000 Btu/hour (Figure 11).

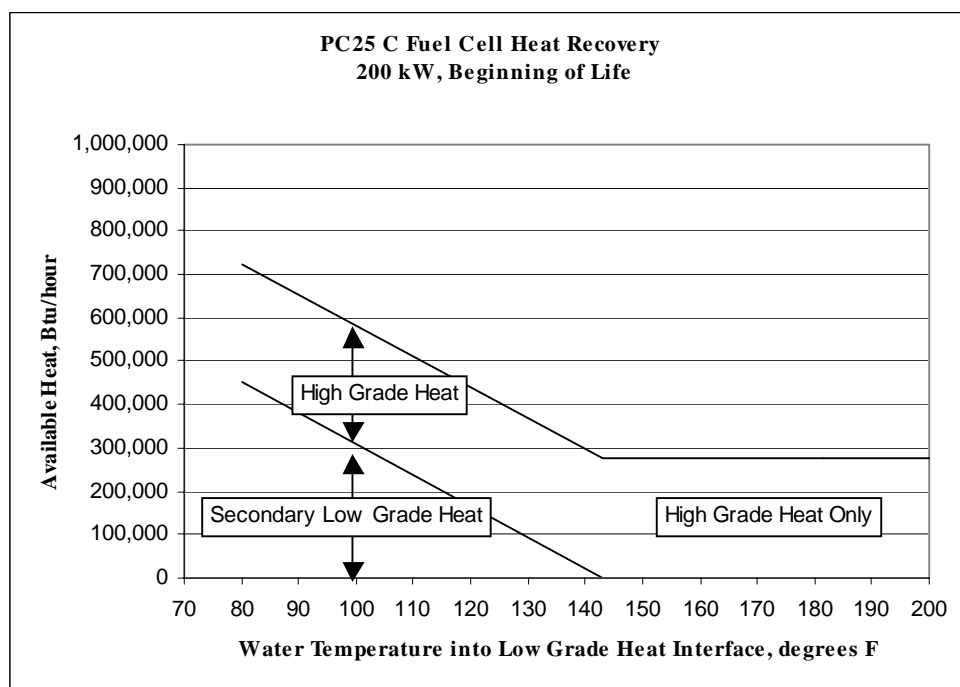


Figure 11. Available PC25 heat recovery, 200 kW, beginning of life.

The data assume a customer side flow rate of 20 gpm or higher into both the low and high grade heat exchangers. It should be noted that the average high-grade heat can vary by $\pm 100,000$ Btu/hour due to the impact of internal feed water operation, which has a cooling effect on the cell stack cooling system. Available secondary low-grade heat will increase as the use of high-grade heat is diminished. The amount of secondary low-grade heat is a function of the customer water temperature into the low-grade heat exchanger as noted on the x-axis of Figure 12.

In Figure 9, under the condition that no high-grade heat is being recovered, the upper diagonal line can be extrapolated to the x-axis to estimate the available low-grade interface heat recovery at inlet temperatures exceeding 143 °F. Approaching the end of power plant life the amount of total recoverable heat is predicted to be approximately 925,000 Btu/hour with the high-grade heat contribution of approximately 475,000 Btu/hour (Figure 12).

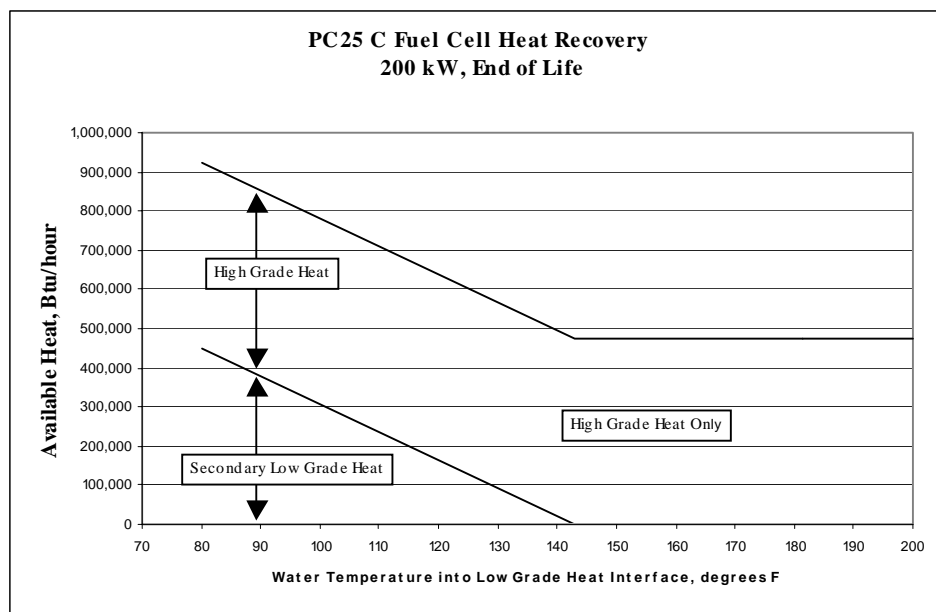


Figure 12. Available PC25 heat recovery, 200 kW, end of life.

Grid Independent BT005A

Objective

Test the capability of the power plant to handle transient power demands created by changing electrical load conditions. The system response was monitored with the FCTec Control and Data Acquisition System (CDAQ), and a Dranetz disturbance Analyzer.

Activity

This test used combinations of both the resistive and motor load banks in a grid independent mode. The test was executed in multiple stages. In each trial, the power plant was loaded with a nominal steady-state electrical load (combinations of resistive and inductive loads). Various motor loads ranging between 5 hp and 50 hp was added to the fuel cell power requirement, and the power plant response monitored. The motors were connected to various systems including centrifugal fans and pumps. Before, during, and after each load addition

test, system voltage, current, wattage, and power quality were recorded along with the nominal ratings of the loads.

Conclusion

This measurement of the fuel cells power plant's ability to manage increasing loads was performed both under the original Modification 1 testing as well as under the Modification 2 testing phase. All data and graphical information were transmitted to ERDC/CERL and UTC Fuel Cells on completion of the tests. The second operation of the grid independent capabilities of the PC25C allowed for a comparison of new power plant capabilities verses a system approaching 22,000 hours of use. Figure 13 identifies the voltage sag indicative of the aging stack. As the power increase is greater, the voltage sag from new stack conditions to half life stack conditions increases proportionally. The system capabilities decreased from 190 kW step ability to 160 kW step capability.

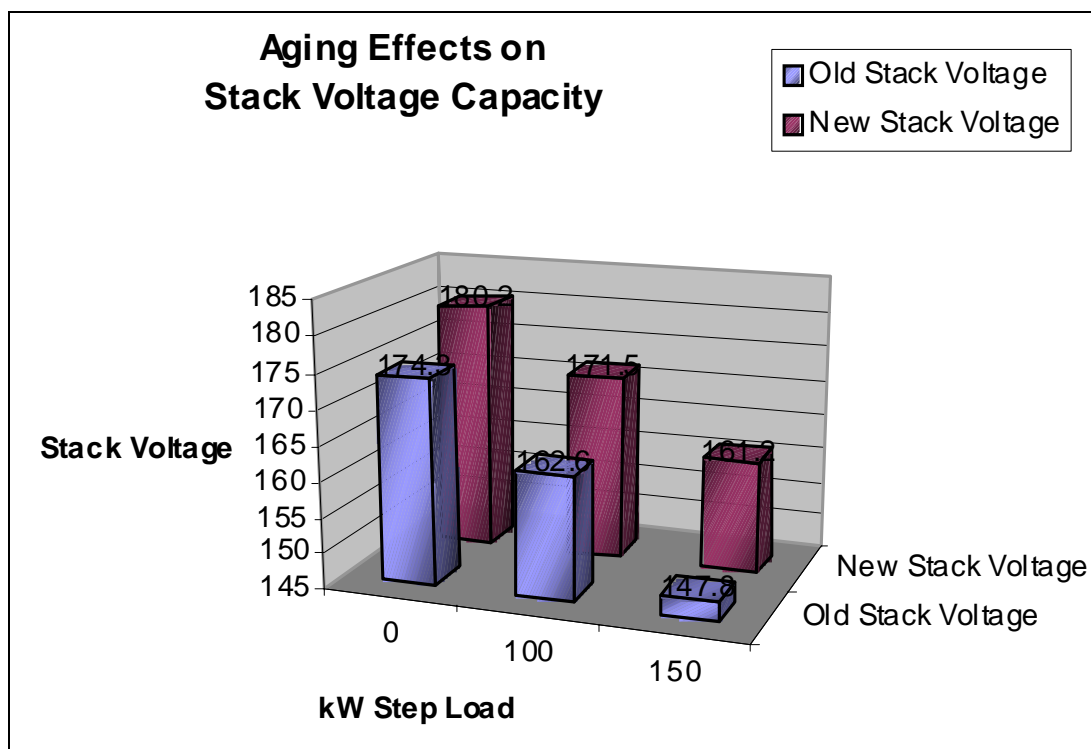


Figure 13. Aging effects on stack voltage under load.

Reviewing the stack Voltage and Current (VI) curve with out respect of parasitic power also indicates the capability reduction. Figure 14 identifies the original stack VI curve with that of the testing performed at 22,000 hours. As the current increases the voltage is now sagging to a point approaching 145 volts.

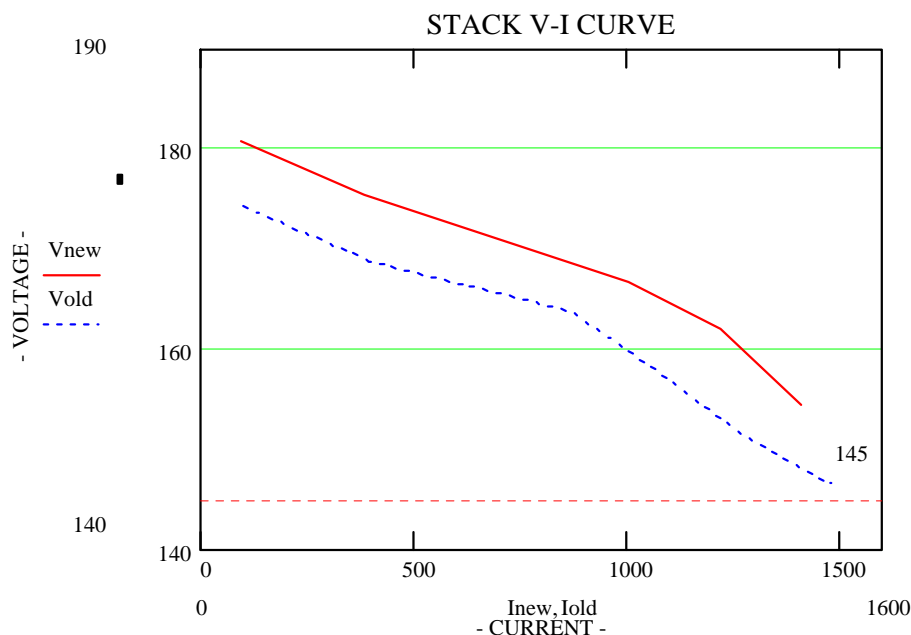


Figure 14. Aging effects on the stack VI curve.

BT005E Grid Independent (VC/APS)

Objective

Define and evaluate requirements to reduce valve cycling during steady state operation. This transient testing will increase the transient capability of the power plant. The final changes will improve valve life, reliability, and life cycle cost. This will be performed by evaluating the feasibility of replacing the existing Cooling Module fan(s) electromechanical control with a Variable Speed Drive (VSD) control.

Activity

New valve actuators were installed to update the power plant to current bill of materials standards. A VSD unit was located within the power plant Electrical Control System to evaluate remote monitoring and control of the Cooling Module.

This change in location required electrical modifications (hardware and wiring) and software reprogramming to the controller to provide for both external monitoring of the Cooling Module glycol exit temperature and generating the necessary VSD control signals. Initial operation of this configuration resulted in several motor failures and respective fuse clearing. Preliminary investigation

identified possible common-mode currents as the failure mechanism and a shielded power cable as a potential corrective measure. This power driven shield is designed to minimize common-mode currents, by providing a low-impedance path to ground for draining ground currents.

The shielded power cable was next installed, replacing the existing power plant / cooling module power cable and testing resumed. Unfortunately, several additional motor failures were experienced, thereby indicating a failure source other than common-mode currents. Further motor investigation and data analysis revealed the presence of significantly large voltage spikes at the motor terminals. These voltage spikes were being generated by the VSD transistorized inverter in conjunction with the long motor cable length (100 ft), and generate a phenomenon called “voltage amplification.” A recognized industry approach to reducing these peak voltages to a benign sinusoidal waveform is the insertion of a “Motor Protection Filter” at the VSD output. Consequently, this type of power filter was ordered, installed and testing resumed.

Specifically, two “Motor Protection Filters” manufactured by Trans-Coil Inc. (TCI) and MTE were procured by UTC Fuel Cells and, installed by CTC. The systems were then evaluated relative to peak voltage levels monitored at the Cooling Module fan/motors. The observed voltage spikes at the motor for each filter were significantly reduced by approximately 50 percent, well below the motor manufacturers specification, and no further premature motor failures were experienced. As part of this evaluation, the new power cable (ECS-to Cooling Module) shield was disconnected to determine its effectiveness relative to incorporation of the filter. These tests concluded that this shielded power cable offered no measurable benefits, and therefore will not replace the existing power cable.

Conclusion

After UTC Fuel Cells reviewed the test data, the TCI filter was selected, primarily due to superior thermal operating characteristics. The MTE filter measured operating temperature was approximately 70 °F above the TCI unit (175 °F vs. 105 °F), and therefore perceived as failure prone when located in high-ambient temperature environments. The power plant / Cooling Module continues to operate with no motor failures since installation of the TCI filter and removal of the power cable shield. Due to this testing, a UTC Fuel Cells engineering design change was implemented to integrate the selected TCI filter with the VSD800 drive in retrofitted applications.

BT005F Grid Independent (PT)**Objective**

To optimize the reformer temperature schedule, improve power plant efficiency and extend reformer tube life. A reduction in operating temperature of the reformer system will provide efficiency during steady state operation.

Activity

Two thermocouples were installed into the reformer burner cavity. These thermocouples duplicate the current reformer control thermocouples as part of the logic that monitors presence of the flame for compliance with the current code requirement of greater than 1400 °F in the burner cavity.

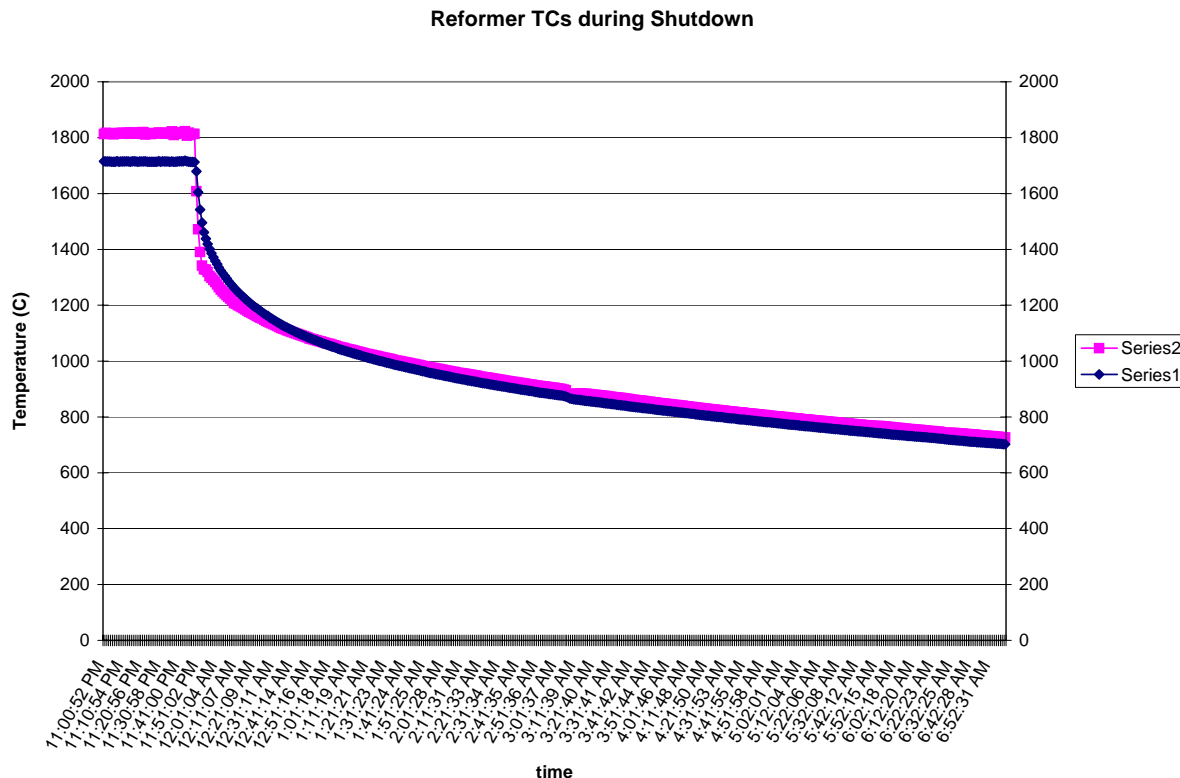
Conclusion

Operating at 150 kW, upon a shutdown event, the temperatures within the reformer drop below 1400 °F within 5 minutes as indicated in Figure 15. After that point, the temperatures slowly sag until the system is restarted. No change in reformer temperatures were made because of the dramatic drop in temperature within the system. Reducing the system operating temperature would have had a detrimental effect on the ability of the system ability to respond to transients.

Water Quality BT008**Objective**

The purpose of the Water Quality testing was to assess the water quality within the fuel cell power plant. Water quality data were taken on a scheduled basis at various points around the power plant including:

- Thermal Management CSA cooling loop (HV431)
- feedwater / DMN450 (HV453)
- water storage tank (TNK450)
- site make-up water.



and dissolved oxygen measurements, concentrations of the following we also documented:

- total suspended and dissolved solids
- total organic carbon
- standard plate count (bacteria)
- silica, chlorine, phosphates, nitrites, sulfates, iron, copper, calcium, sodium and magnesium.

Conclusion

Bad water chemistry within the CSA cooling loop can cause the build-up of deposits at critical locations in the CSA coolers, which can lead to restricted cooling flow, high cell temperatures, and potentially stack failure. It is therefore imperative that water quality within (and provided to) the Thermal Management System (TMS) be maintained.

The Water Treatment System (WTS) within the PC25C treats condensate removed from the process exhaust streams in the condenser as well as makeup water required during low power operation. Dissolved carbon dioxide is removed from the condensate via a degasifier column prior to entering the storage water tank. Water from the water tank is circulated through 2 cu ft of activated charcoal to remove organic materials and 8 cu ft demineralizer resin to deionize the water. Periodically some of this deionized water provides feedwater to the CSA cooling loop to make up for the FPS process steam and blow down requirements.

In general the PC25 field instrument analysis results agreed with the results from the laboratory instruments in both level and trend when compared on a yearly basis (Table 9). The lab equipment demonstrated higher levels of pH and dissolved oxygen at most locations relative to the field instruments. Both types of equipment showed the conductivity level expected for the PC25. It was also expected that feedwater conductivity would be lower than CSA cooling loop conductivity. Turbidity was not compared since the instruments are calibrated for different units

Table 9. Water quality comparison PC25C Power Plant 9194.

	Analysis Instrument	Conductivity Us		pH		Dissolved Oxygen	
	Location	2000	2002	2000	2002	2000	2002
Feedwater	Field	0.12	0.17	5.90	6.46	4.30	5.20
Feedwater	Lab	0.37	0.36	6.37	6.53	4.35	6.47
Site make-up water	Field	1.01	2.72	5.39	5.30	5.92	6.20
Site make-up water	Lab	0.85	2.25	5.68	5.55	6.48	6.63

	Analysis Instrument	Conductivity Us		pH		Dissolved Oxygen	
	Location	2000	2002	2000	2002	2000	2002
CSA cooling loop	Field	0.25	0.24	5.85	5.65	3.58	3.60
CSA cooling loop	Lab	0.27	0.47	6.09	5.77	3.95	4.92
Water tank	Field	20.9	7.64	5.42	4.85	4.42	5.60
Water tank	Lab	18.78	6.80	5.69	5.08	4.55	6.32

The average readings from Table 9 are generally typical of the PC25 fleet experience.

Modification 3 Activities

Objective

National Defense Center for Environmental Excellence (NDCEE), operated by CTC, developed and validated residential scale fuel cell standardized evaluation test protocols suitable for independent assessments of the applicability of individual fuel cell products manufactured by the fuel cell community. Sub-tasks completed within this activity included:

NDCEE surveyed fuel cell developers to determine the size, pertinent features, cost, and availability timeframe of existing and/or planned commercial products in the 1 kW to 30 kW range. NDCEE surveyed the Fuel Cell Developers to obtain the referenced survey information and identify the developers testing needs and the DOD FCTec testing capabilities. Plug Power was the only supplier capable of providing a system to meet the commercial needs of a natural gas fuel powered fuel cell system.

NDCEE consulted with the existing fuel cell related codes and standards committees and organizations to ensure compatibility and approval of code agencies. NDCEE's focus within this task will be concentrated on the following code areas: ANSI Z.21.83, NFPA 853, NFPA 70 Article 692, ASME PTC 50, and IEEE P1547.

NDCEE consulted with the National Rural of Electric Cooperation Associate (NRECA) to determine needs related to the assessment of fuel cell technology for their individual applications. Attendance and participation at the NRECA quarterly fuel cell user's group meeting allow for the review of the military and fuel cell user community application needs (e.g., telecommunication, equipment maintenance, laundry, restaurant and clinical facilities). Attendees at these

meetings typically included members from the DOD, DOE, Fuel Cell Developers and Fuel Cell Commercial and Industrial End Users. Information collected from these meeting was used in the completion of the development of the Fuel Cell Evaluation Test Protocol.

The background research, communication and evaluation of the fuel cell systems and users needs resulted in the development of a standardized Fuel Cell Evaluation Test Protocol for residential sized fuel cell systems. These preliminary Test Protocols are to be used to support the validation tasks of residential sized fuel cell power plants within the DOD *FCTec*.

Activities

The individual test protocols referenced within the Appendixes of this document were developed to provide the guidelines, strategies, specifications, and concepts to ensure consistent testing strategies for all residential sized fuel cell power plants tested within *FCTec*.

Details of the guidelines, strategies, specifications, and concepts of each test protocol can be reviewed in each of the appendices referenced. A brief overview of the created test protocols follows.

Peak Load Shutdown Test

The objective of the Peak Load Shutdown Test is to determine the peak load supply power of the fuel cell being evaluated for both constant and changing electrical loads. Primary evaluation shall concentrate on the fuel cell's ability to supply power without the complicating factors of large inductive transients and large impulse current. Initial testing shall consist of various levels of resistive loading. Appendix J gives further details.

Sustained Load Test

The objective of the Sustained Load Test is to determine the maximum sustained load capable from the fuel cell power plant that is being evaluated for both constant and changing electrical loads. Primary evaluation concentrates on the fuel cell's ability to supply power without the complicating factors of large inductive transients and large impulse currents. Initial testing shall consist of various levels of resistive loading. Appendix K gives further details.

Sustained Load Step Test

The objective of the Sustained Load Step Test is to determine the fuel cell power plant capabilities of operating with impulse load transitions, up to and including 100 percent of the Sustained Load that was determined during the Sustained Load Test. Primary evaluation shall concentrate on the fuel cell's ability to supply power without the complicating factors of large inductive transients and large impulse currents. Initial testing shall consist of various levels of resistive loading. Appendix L gives further details.

Overload Test

The objective of the Overload Test is to determine the fuel cell power plant's capability of operating with impulse transients up to 200 percent of the sustained load capacity. Primary evaluation shall concentrate on the fuel cell's ability to supply power without the complicating factors of large inductive transients and large impulse currents. Initial testing shall consist of various levels of resistive loading. Appendix M gives further details.

Residential Profile Test

The objective of the Residential Profile Test is to verify the fuel cell power plant's capability of operating in a residential setting, over a 5-day period. In this test, a profile will be established, and residential electrical appliances will be used to serve as the load. Loads and load changes shall be automated so that each fuel cell power plant being tested is subjected to the same load pattern. Appendix N gives further details.

Residential Profile Test—Temperature and Humidity

The objective of the Residential Profile with respect to Temperature and Humidity Test is to verify the fuel cell power plant's capability of operating in a residential setting, under conditions of high/low humidity, and high/low temperatures over a 24-hr period. The fuel cell power plant being evaluated shall be placed in the temperature and humidity chamber for testing. The test table lists the temperature and humidity settings for each test. When the temperature and humidity are stable, 24 hrs of the Residential Profile Test shall be performed. Appendix O gives further details.

Combined Heat and Power Test

The purpose of the Combined Heat and Power Test is to measure and map the thermal output of a given Fuel Cell Power Plant under various load conditions. A Thermal Load Bank with all of the appropriate measurement and control devices will be used as the testing device. A Computerized Data Acquisition system will be used to capture and store collected data. Appendix P gives further details.

15 Amp Circuit Breaker Overload Test

The objective of the 15 Amp Breaker Overload Test is to determine the fuel cell power plants capability to successfully open a 15-amp breaker under an overload condition, while maintaining power to circuits that are not overloaded. Appendix Q gives further details.

15 Amp Breaker Short Circuit Test

The objective of the 15 Amp Breaker-Short Circuit Test is to determine the fuel cell power plant's capability to successfully open a 15-amp breaker when subjected to a short circuit, while maintaining power to other circuits. Appendix R gives further details.

Power Grid Simulator Test

The objective of Grid Simulation is to develop a characteristic profile for a given residential scale fuel cell power plant with respect to grid variations (transients, voltage surges/sags, frequency deviations, voltage phase differentiations, and waveform distortions). Overall performance of the residential scale fuel cell power plant will be determined for each variation. Appendix S gives further details.

NDCEE validated the Fuel Cell Evaluation Test Protocol by testing the residential scale Plug Power fuel cell system. The validation testing took place within the DOD FCTec. The Plug Power fuel cell system was operated on natural gas fuel supply during the anticipated validation phase. Validation of the test protocol was limited to using the existing equipment within the FCTec and the existing capabilities of the fuel cell system.

Conclusion

Ten preliminary test protocols developed by NDCEE in support of testing and validating the performance and reliability of residential sized fuel cell systems were completed. These test protocols are viewed as living documents in that the existing protocols may be revised, or additional protocols created, to incorporate additional testing procedures as the fuel cell system needs evolve.

Two test protocols were validated due to the limited capabilities of the Plug Power Grid Connected system. The available Plug Power system only allowed the validation of the Combined Heat and Power Test, and the Grid Simulation Test.

3 Summary

This work established test protocols, tested, and evaluated a UTC Fuel Cells 200 kilowatt (kW) PC25C Phosphoric Acid Fuel Cell Power Plant (PAFC) to achieve life-cycle-cost reduction and performance improvements. CERL and CTC also established a National Resource that can provide independent, unbiased testing and validation of fuel cell power plants for military and commercial applications. This test center (FCTec) provides the capability to significantly support the development and commercialization of fuel cell power plants.

The installation of a PC25C within CTC's ETF was documented to develop a history of segmented costs for fuel cell installations of similar nature. CTC demonstrated that sub-contractors with little or no prior "fuel cell" experience could perform fuel cell installations economically. With the proper training and management, local contractors can successfully install large fuel cell power plants.

A temperature/humidity controlled environmental system and a shock/vibration system to support small, low power fuel cell testing was acquired and installed. These devices have been sized to accept fuel cell systems under 10 kW capacity, and will be applicable to both stationary and transportation fuel cells.

Testing was provided to validate baseline and performance enhancements of the PC25C. The tests were designed to provide UTC Fuel Cells and ERDC/CERL with data necessary for the evaluation of the PC25C performance. The testing did support the validation of the fuel cell operating capabilities, operational characteristics, and system responses.

Overall, the results of the testing performed by CTC at FCTec provided the basis for ongoing product development to obtain reliability and life cycle cost objectives and to expand applications for the PC25C. Because of the success of the FCTec testing, additional modifications to Task 211 were added to continue testing on the UTC Fuel Cells PC25 as well as to develop a residential sized standardized test protocol in coordination with the National Rural Electric Cooperative (NRECA).

Acronyms and Abbreviations

<u>Term</u>	<u>Spellout</u>	<u>Term</u>	<u>Spellout</u>
ASTM	American Society for Testing and Materials	N ₂	Nitrogen
CTC	Concurrent Technologies Corporation	NDCEE	National Defense Center for Environmental Excellence
CAM	Contract Agreement Memorandum	NH ₃	Ammonia
CDAQ	Control and Data Acquisition	NO ₂	Nitrogen Dioxide
CERL	Construction Engineering Research Laboratories	NO _x	Nitrogen Oxides
CH ₄	Methane	NRECA	National Rural Electric Cooperative Association
CO	Carbon Monoxide	O&M	Operation and Maintenance
CO ₂	Carbon Dioxide	P&ID	Process & Instrumentation Diagram
CSA	Cell Stack Assembly	PAFC	Phosphoric Acid Fuel Cell
DOD	Department of Defense	PC25C	UTC Fuel Cells 200 kW Phosphoric Acid Fuel Cell Power Plant
ECS	Electronic Control System	PCS	Power Conditioning System
ERDC	Engineering Research and Development Center	PEMFC	Proton Exchange Membrane Fuel Cell
ETF	Environmental Technology Facility	PMP	Program Management Plan
EPA	Environmental Protection Agency	PTP	Program Test Plan
FC <i>Tec</i>	Fuel Cell Test and Evaluation Center	RFQ	Request for Quotation
FRP	Fiberglass Reinforced Plastic	RNG	Reference Natural Gas
gpm	Gallons Per Minute	SOW	Statement of Work
FTP	File Transfer Protocol	SO _x	Sulfur Oxides
H ₂	Hydrogen	THC	Total Hydrocarbons
HVAC	Heating, Ventilation and Air Conditioning	TLB	Thermal Load Bank
ISTA	Information, Science, and Technology Agency	VOC	Volatile Organic Compound
kW	Kilowatts		
LP	Liquid Propane		

Appendix A: Initial Report Task 211 (28 December 2000)

1.0 Introduction

This report documents the activities performed by *CTC* for the first 2 years of Task N.211, U.S. Army ERDC/CERL. This report fulfills the requirement of Statement of Work (SOW) paragraphs 2.9.1 and 2.9.2 FY98 and FY99 Final Report. Provided is a brief summary of the initiation of this program, the fuel cell operating characteristics (baseline and extended tests), equipment procured, and lessons learned.

It is the objective of this U.S. Army ERDC/CERL funded program to provide testing and evaluations, in cooperation with UTC Fuel Cells of a PC25C. The focus of this test and evaluation effort is in support of life-cycle-cost reduction and performance improvement goals. It is also an objective of this program to provide the capability for independent design assessments of alternative technology fuel cell system configurations and components for achieving lower life cycle cost either through reduced capital cost, reduced operation and maintenance (O&M) costs, or increased performance and reliability.

2.0 FCTec

The DOD *FCTec* was designed for simple operation and maximum flexibility. It has been designed to allow future expansion in terms of additional fuel cells, as well as to accommodate future testing requirements. Much of the test equipment within the *FCTec* including electrical and thermal load banks has been assembled on portable skids for optimum space flexibility. The Control and Data Acquisition (CDAQ) system is located in the proximity of the fuel cell, allowing optimum efficiency in setting up and executing tests. All utilities are available nearby for economical connection. A propane gas fuel feed can be supplied through the use of a temporary outdoor tank system immediately outside the *FCTec* area. Power plant exhaust is drawn through a hood and ductwork by a

roof-mounted fan that exhausts the flow outside the building. The *FCTec* occupies space within *CTC*'s existing ETF high bay area, as shown in Figure A1.

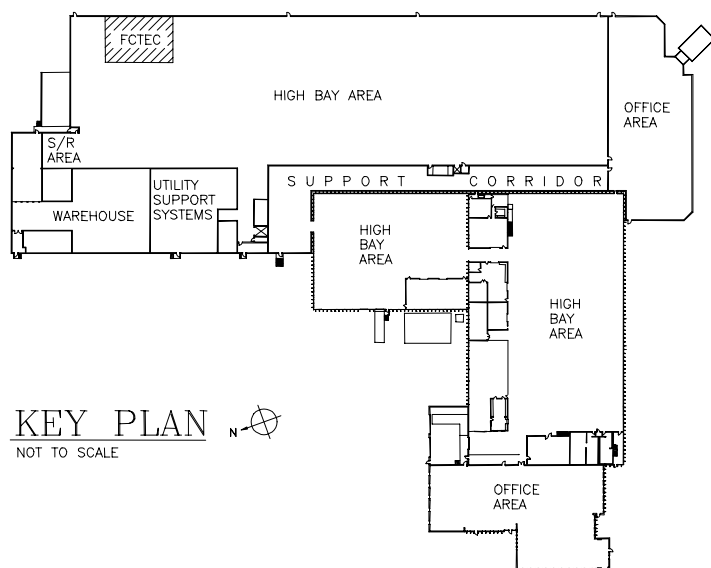


Figure A1. Key plan.

The testing and evaluation requirements identified by UTC Fuel Cells and ERDC/CERL for the PC25C were the basis of the design, testing capabilities and layout of *FCTec*. Modifications to *FCTec* and the enhancement of additional testing equipment were also required to accommodate the test and evaluation requirements for the Avista PEMFC power plant. These two test and evaluation programs have defined the initial design and testing capabilities of *FCTec*.

2.1 Background

ERDC/CERL, *CTC*, and UTC Fuel Cells, through meetings and reviews have collaborated to establish the PC25C Program Test Plan (PTP) document. The content of the document was established as a consensus plan to successfully achieve the goals of the overall program for the test and evaluation of the PC25C. The PTP defines the guidelines, strategies, specifications, and concepts to ensure a complete and consistent testing plan with the necessary engineering requirements for a successful program.

The PTP document provided the overall requirements and technical plan for *CTC* to implement the testing program for the PC25C. The PTP describes the general requirements for baseline power plant evaluation, as well as, improved power plant evaluations. In addition, this plan documented the control and data acquisition strategies, operations, data formatting reporting strategies, and the

configuration management plans for the physical plant, operation, maintenance, and testing of the PC25C.

The first draft of this document was created and distributed as a shared project deliverable document to ERDC/CERL and UTC Fuel Cells on 17 December 1998. On 29 February 2000 a revision was completed on this document and submitted again as a shared project deliverable. The revision incorporated the test and evaluation requirements of the PC25C that would be covered under the year two U.S. Army ERDC/CERL funding.

Also, under the year two U.S. Army ERDC/CERL funding, *CTC*, Avista, and ERDC/CERL collaborated to establish the SOW document that identified a consensus plan to successfully achieve the goals of the overall program for the test and evaluation of an Avista 720W PEMFC. The SOW defined the specifications and test concepts for a successful accomplishment of this program's goals.

Figure A2 provides a simplified schematic representation of the major *FCTec* facility capabilities currently used to support the test and evaluation of the PC25C. Details of the specific aspects of *FCTec* testing capabilities developed from the PTP and Avista's SOW documents are provided in the following sections.

2.2 Thermal Load Bank

A single thermal load bank system was designed and procured by *CTC* to support the test and validation of the high-grade and low-grade heat recovery of the PC25C. This system can interface with as many as two fuel cell heat exchangers simultaneously. It is equipped with flow, temperature and pressure sensors and can handle flow rates up to 100 gpm and fluid temperatures up to 300 °F. The system is constructed out of stainless steel and may be directly integrated to fuel cell stacks. A process diagram of the thermal load bank is shown in Figure A3.

2.3 Electrical Load Banks

The electrical load banks may be used for both short and long-term electrical load testing in grid-independent mode of operation. The load banks designed and procured by *CTC* provide power plant loads that can be freely applied and removed without concern for affects on other surrounding equipment or systems. This equipment, as shown schematically in Figure A4, allows total control of power plant loading from 0 percent through overload, and with various combinations of resistive and inductive (i.e., motor) loads.

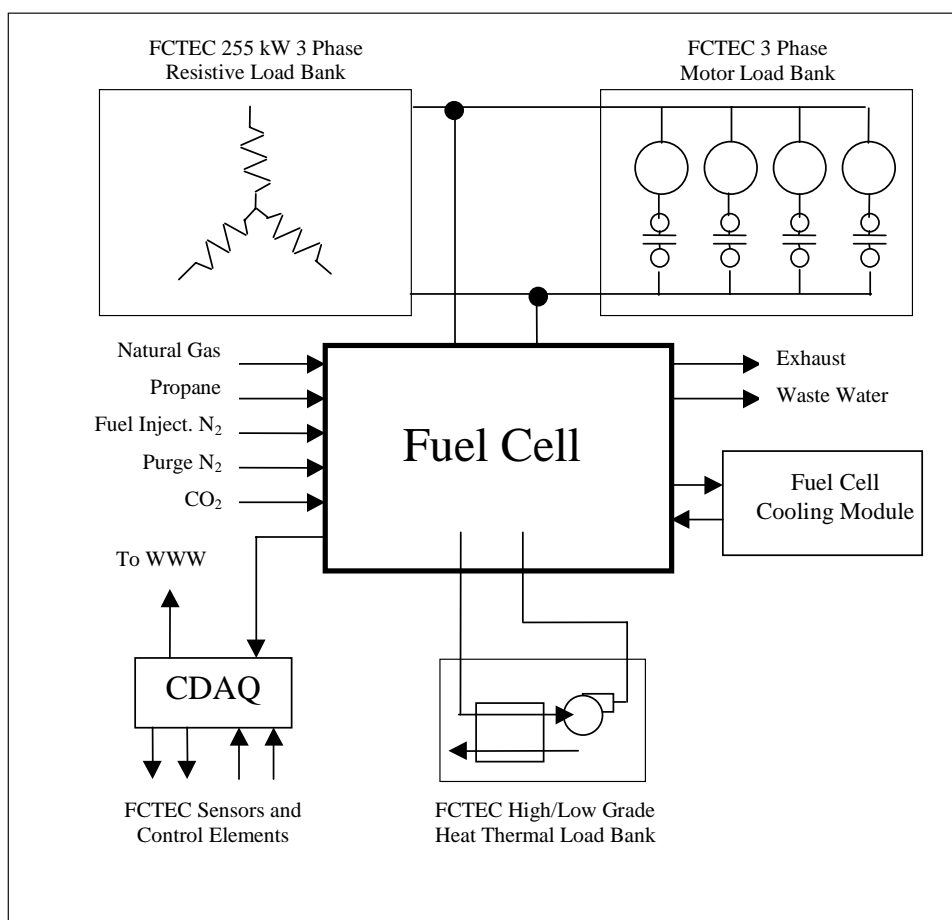


Figure A2. Overall process schematic.

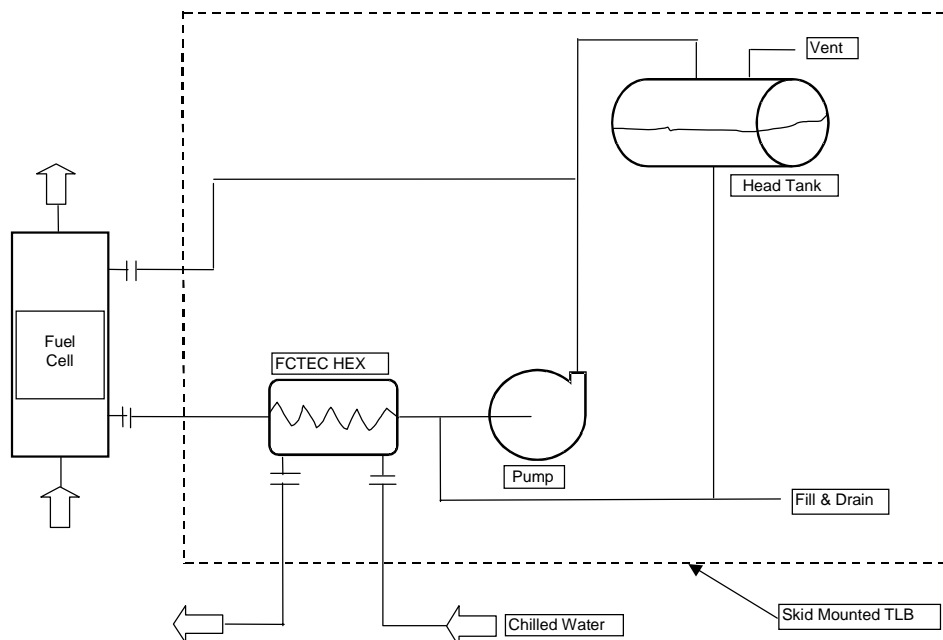


Figure A3. Thermal load bank diagram.

2.3.1 Resistive Load Bank

The resistive load bank was designed and procured that can provide loads up to 255 kW with load changes as small as 5 kW. The system is equipped with multiple contractors that enable loading changes to be made automatically during test execution. In-line voltage and current sensors are provided to acquire PC25C response characteristics.

2.3.2 Motor Load Bank

The motor load bank consists of fan, pump and dynamometer motor skids. In conjunction with the resistive load bank, these systems can simulate a wide range of practical electrical loads. The motor load bank test range is from 5 to 85 hp in various configurations, including soft start and variable speed capabilities. Each system is equipped with voltage, current and kilowatt sensors.

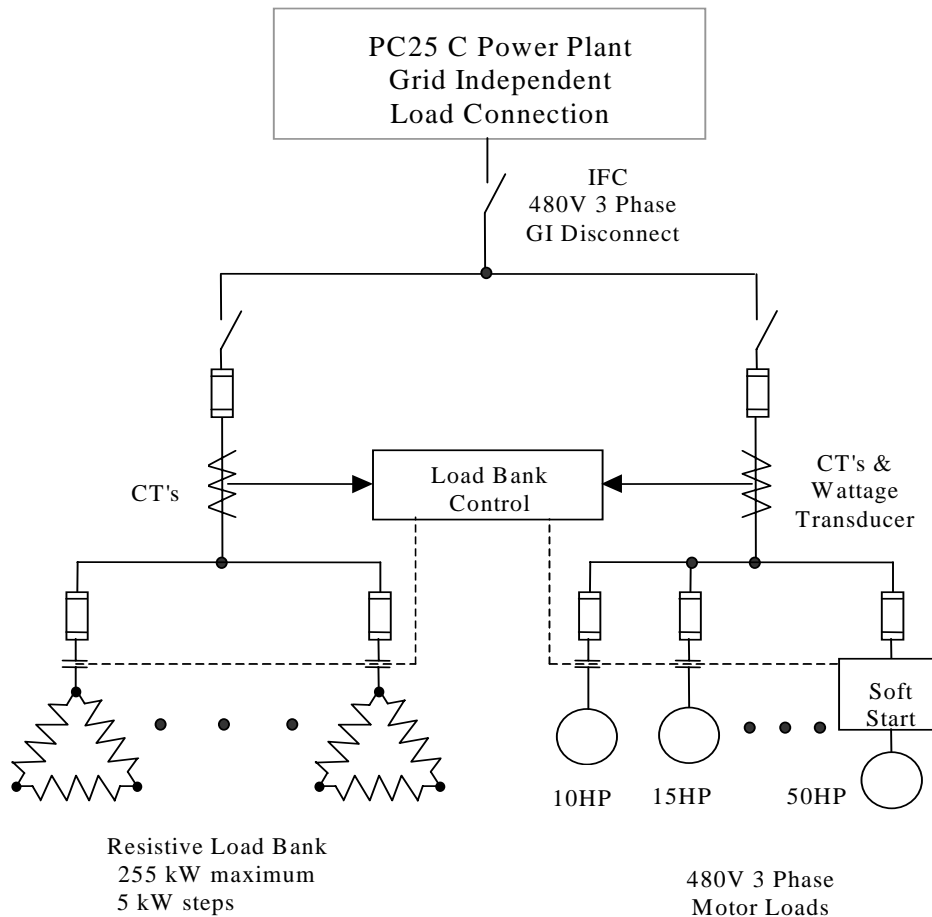


Figure A4. Electrical load bank block diagram.

2.4 Control and Data Acquisition System (CDAQ)

The CDAQ is a PC-based system that was designed, constructed and executed by CTC engineers. This system consists of two Pentium II based personal computers, various sensors and interconnecting hardware. The purpose of the CDAQ is fourfold:

6. Provide an automated means for collecting critical process and operating parameters which will be required to assess the results of the tests performed on the fuel cell
7. Provide long term storage for both the data acquired in item 1 and for data acquired as a result of other, manually collected, measurements including the gas analysis tests.
8. Provide a means for electronically disseminating the data to CTC, UTC Fuel Cells, Avista, and ERDC/CERL personnel for analysis and publication.
9. Control of test center elements to provide automated test execution where possible. This will expand the number of hours available for performing fuel cell tests.

The CDAQ consist of four integrated subsystems. These include the existing data acquisition capabilities built into the PC25C by UTC Fuel Cells, additional data acquisition capabilities provided by FCTec, a database repository for archiving collected data, and a web based operator interface, which allows the archived data to be viewed and/or uploaded for analysis. Figure A5 shows the complete CDAQ system. Each of the subsystems comprising the CDAQ system is described below.

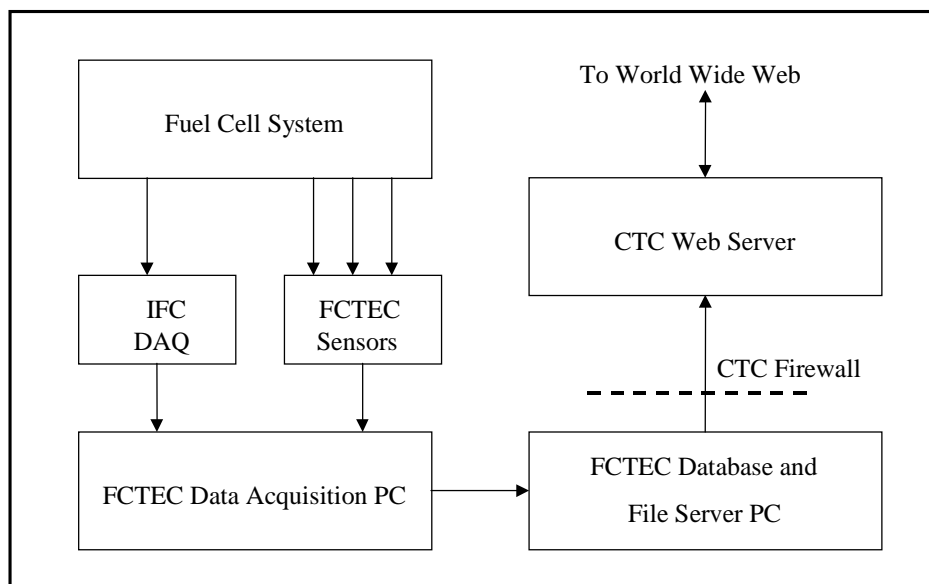


Figure A5. Control and data acquisition block diagram.

2.4.1 UTC fuel cells data acquisition system

The fuel cell as delivered by UTC Fuel Cells, already incorporated a substantial data acquisition capability. UTC Fuel Cells has identified approximately 300 operating parameters, which are electronically accessible from their control system. These include such items as kilowatts of power generated, currents, voltages, power factors, and other critical operating parameters. UTC Fuel Cells provided *CTC* with the communication protocol required to access these parameters via a spare serial port on the fuel cell controller. *CTC* used the protocol to develop a software application that acquired the data from the UTC Fuel Cells controller and archived it in the CDAQ Database.

2.4.2 FCTec data acquisition system

Several critical parameters required for the baseline testing are not available from the UTC Fuel Cells Data Acquisition System. These include various flow rates, system pressures, temperatures, currents, and other parameters identified throughout this document. *CTC* selected and installed these additional sensors into the *FCTec*. Data is automatically acquired from these sensors and stored in the CDAQ Database.

2.4.3 CDAQ database

Data acquired from both the UTC Fuel Cells Data Acquisition System and the *FCTec* Data Acquisition System is stored in a relational database. *CTC* developed the necessary data tables for test result storage, the necessary interfaces to communicate and accept data from the UTC Fuel Cells and *FCTec* Data Acquisition Systems and the necessary interfaces to the World Wide Web for accessing the data from the tables. In addition to the raw data storage, other information pertinent to the tests was also stored. These data include the test name, time and date when the test was performed, initial setup up conditions for the fuel cell, and other information of interest to the test evaluators.

2.4.4 Internet Access to CDAQ Data

The data collected and stored in the CDAQ Database is also available for viewing and/or downloading via a File Transfer Protocol (FTP). *CTC* developed the necessary modules that allow the test data to be viewed and downloaded via the FTP site. Access to this site and the test data are password protected.

2.5 Emissions Monitoring

CTC procured laboratory instrumentation and a Continuous Emission-Monitoring (CEM) trailer in support of satisfying the testing requirements outlined within several baseline tests within the PTP. The laboratory instrumentation allowed direct reading, portable, air-monitoring capabilities for recording Hydrogen, Carbon Dioxide, Oxygen, Nitrogen, Methane, and Carbon monoxide. This equipment consisted of:

- Myron L – portable meter for measuring water conductivity
- Gelman – filter unit for turbidity testing
- CHEMet – kits for Dissolved Oxygen measurement
- Perkin-Elmer Gas Chromatograph – used to measure selected gases
- Gas sampling valve, columns and detector to allow for the analysis of light gases
- Testo Model 300XL – was used to measure oxygen, carbon dioxide, carbon monoxide and oxides of nitrogen
- Methane sensor – detecting methane at two alarm ranges.

The CEM trailer is a fully integrated system that is used to monitor fuel cell system stack emissions. The mobile system is equipped with instrumentation used to monitor and record CO, O₂, CO₂, NO₂, THC, and SO_x. Additional equipment procured to the CEM trailer equipment included:

- Analytical column, gas syringes, and gas standards – used with gas chromatograph to allow for the analysis of hydrocarbons in stack gases
- Velocity probes and sampling equipment – used to compliment existing stack sampling equipment for determining stack velocities
- Dry gas meter and a calibrated flow meter – used to assist in preparing calibration standards and measure gas volumes and flows.

2.5.1 Water Quality Analysis

CTC procured hand-held and laboratory instrumentation to support the water quality analysis requirements outlined within the PTP test. *CTC*'s hand-held instrumentation provides the capabilities to capture and record conductivity, turbidity, dissolved oxygen and pH. *CTC*'s laboratory instrumentation provides the capability to conduct EPA approved laboratory procedures/tests to capture and record conductivity, turbidity, dissolved oxygen, pH, metals, ions, silica, bacteria, total dissolved and suspended solids, and total organic carbon.

2.6 Fuel Supply

For normal operation, *FCTec* can provide natural gas fuel through the existing ETF natural gas pipeline. *FCTec* is currently capable of supporting dual fuel testing. Facility modifications have been completed that will also allow a propane fuel supply system to be installed. The current arrangement will allow a propane system consisting of one 1,000 gallon tank to be position just outside of *FCTec* and connected directly to the fuel supply line of the PC25C. The Natural gas and propane feed lines are both equipped with instrumentation for the capture and recording of flow rates, fuel line supply pressures and incoming gas temperatures

2.6.1 Fuel Blending System

FCTec is also equipped with the instrumentation and hardware to allow other gases to be injected directly into the fuel supply line. A manifold system was designed and assembled by *CTC* that provides the capability to control the injection of gases directly into the fuel supply line. The system is currently configured to support Nitrogen gas injection.

2.7 Temperature/Humidity Environmental System

In support of the Avista PEMFC test and evaluation program, *CTC* procured a Temperature/Humidity Environmental System. This system is capable of conducting environmental testing of low-power fuel cell systems and can achieve temperature ranges of -10 to +140 °F and humidity ranges of 35 to 95 percent on rated loads.

2.8 Vibration Test System

CTC also procured a Vibration System in support of the Avista PEMFC test and evaluation program. This system meets the requirements of ASTM, the Information, Science, and Technology Agency (ISTA), and other industry-standards product test specifications. The vibration system is used to simulate shock and vibration effects on low-power fuel cell systems. The capabilities on rated loads of the system are:

- 13,000 lb. Force
- 70 in/second velocity
- 5 Hz to 2000 Hz frequency
- sine, random, and shock profiles.

2.9 FCTec Promotional Activities

To assist with the promotion of the DOD FCTec, CTC and ERDC/CERL collaborated to create a program Fact Sheet and Website. These activities were completed to provide information about the test center to fuel cell manufacturers.

2.9.1 FCTec Fact Sheet

The FCTec Fact Sheet outlines the background, objectives, capabilities and systems of FCTec. This fact sheet provides photographs of the test systems currently installed within the FCTec. The fact sheet has been distributed to all FCTec visitors and at fuel cell technology seminars and conferences that CTC staff attend.

2.9.2 FCTec Web Site

The FCTec Website can be accessed at <http://www.fctec.com>. This site also outlines the background, objectives, capabilities and systems of FCTec along with the current clients and the objective of each test and validation program. This site provides photographs of the test systems currently installed within the FCTec.

3.0 Installation

At the request of ERDC/CERL, the procedures and costs associated with the FCTec PC25C installation and start-up were documented by CTC. This information is provided within this Final Report. The following sections summarize the background, the PC25C installation within FCTec, DOD PC25C installation comparisons and CTC's installation recommendations resulting from our experience.

3.1 Background

CTC was tasked with determining an optimum site within available CTC facilities for the location of the FCTec. CTC prepared a suitable site for the execution of the test program and acquired the necessary equipment and instrumentation to satisfy the test program requirements. CTC designed, built and installed facility modifications necessary to accommodate the fuel cell installation consistent with the requirements in the Program Management Plan, including surrogate systems to supply the necessary capabilities for the electrical and thermal outputs of the fuel cell.

The design takes into account provisions for future expansion of the *FCTec* to accommodate additional fuel cells and/or different fuel cell technologies. *CTC* designed and installed a central computer system in close proximity to the fuel cell for data acquisition and operation control.

CTC received a government supplied PC25C manufactured and delivered by UTC Fuel Cells. ERDC/CERL funded the fuel cell acquisition and installation through the start-up and acceptance test phase of the contract. UTC Fuel Cells was responsible for the power plant installation, including start-up and acceptance testing, at the *CTC* prepared site. *CTC* actively participated in the installation, initial start-up, and acceptance test as support to UTC Fuel Cells. *CTC* and UTC Fuel Cells worked together to install the hardware connections that physically integrate the power plant with the *FCTec* equipment.

3.2 *FCTec* PC25C Installation

The *FCTec* was developed within *CTC*'s ETF. The PC25C manufactured by UTC Fuel Cells was installed within this area. The primary installation contractor was GBC Electrical Services, which used local subcontractor support to accomplish the installation requirements. The major subcontracts required to support the installation were: Electrical, Mechanical, Rigging Services, and HVAC/ Ventilation.

The indoor application of the PC25C at the *FCTec* site required a ventilation system to extract the power plant exhaust. *CTC* was responsible for the procurement and installation of the ventilation system with UTC Fuel Cells providing the engineering, equipment specification, and design drawings. The cost of the ventilation system was not included in the base installation contract with GBC Electrical Services but is reflected in the cost information.

GBC Electrical Services' contract with UTC Fuel Cells for the *CTC FCTec* fuel cell installation was \$67,989 dollars. That cost is segmented into materials, (\$36,924), labor, (\$27,600), and overhead and profit, (\$3,465). Nontypical items associated with this installation were the indoor exhaust ventilation system and the fiberglass reinforced plastic (FRP) elevated grating used to cover the heat recovery piping exiting the power plant. The FRP grating was used to facilitate easy and unobstructed walking access near the high traffic area around the PC25C. The cost for this grating was \$3,865 and was included in the UTC Fuel Cells contract.

CTC was responsible for the installation of the exhaust ventilation system. The cost of the complete ventilation system installation was \$10,500. *CTC* subcon-

tracted this work to a local Heating Ventilation and Air Conditioning (HVAC) contractor through a competitive bid process.

Table A1 lists actual installation cost breakdown by discipline and the corresponding percentages as compared to the total.

Table A1. Task 211, installation costs by discipline.

Actual Installation Costs						
Electrical	Mechanical	Rigging	FRP Grate	Resin/Glycol	Overhead	Total
\$19,954	\$27,763	\$9,600	\$3,865	\$3,342	\$3,465	\$67,989
29%	41%	14%	6%	5%	5%	100%

Note that approximately \$6,000 in UTC Fuel Cells administrative costs is not included in the total installation cost of \$67,989 reported by GBC Electrical. The UTC Fuel Cells reported cost was \$73,899.

The electrical and mechanical work represented 70 percent of the total project cost with mechanical being the largest cost at 41 percent. This is consistent with the high quantity of piping, used to supply the power plants needs as well as the users heat recovery needs. Rigging and final placement of the power plant accounted for approximately 15 percent of the total. Startup materials and overhead requirements were 10 percent of the project cost.

A log of work hours by subcontract discipline was maintained during the fuel cell installation to identify labor requirements between the designated trades. Table A2 illustrates the total hours that were required for each discipline to complete the installation.

Table A2. Task 211, installation labor by discipline,

Labor Hours by Discipline				
Rigging/Crane	Mechanical	Electrical	Supervision	Ventilation *
64 hrs	232 hrs	80 hrs	176 hrs	206 hrs
Total = 758 labor hours				
* Ventilation system by CTC – included in the total work hour requirement.				

The FCTec installation was straightforward and required only short utility runs coupled with ideal working conditions. This is reflected in the lean work-hour total that was required to complete the job. The FCTec installation spanned a 6-week period with the bulk of the work being completed in 4 weeks.

3.3 FCTec PC25C Installation Comparison with other DOD units

The simplification and standardization of typical practices for the installation of the PC25C is imperative to reduce the cost of fuel cell systems. Many engineers and contractors are not familiar with fuel cell designs and are hesitant to consider them as typical distributed generation installations. Diesel generators have been in the engineering and construction arena for many years and everyone involved is very comfortable with their procurement and installation. This familiarity leads to lower costs for their integration into the electrical and mechanical systems. As fuel cell power plants become more common, they too will become second nature to the contract industry.

The development of a site installation evaluation document to simplify and standardize the estimating process for all PC25C locations will assist this transition. The information systematically estimates basic power plant installation requirements and any options that are desired. The spreadsheet accounts for geographic cost indexes for different labor and material rates across the United States and Canada to apply a rating cost factor after the estimate is developed. In addition, indirect costs are accounted for in developing the total cost estimate.

A typical PC25C installation (outside installation using the standard heat recovery capability) will include the following basic components:

- concrete pad for the Fuel Cell, designed for the structural weight of the system and site geological requirements
- concrete pad for the air cooling module if located separately from the fuel cell
- 6-ft high chain link security fence surrounding the fuel cell and cooling module
- system water piping connections, supply and drain
- nitrogen gas system for purge requirements
- one data line and one voice telephone line
- electrical interconnection to grid
- heat recovery thermal interface
- standard instrumentation.

Non-typical items associated with PC25C installations (which are site specific and will require input from engineering and operation personnel at the specific site) may be as follows:

- thermal storage equipment, for the possibility of increased use of the available thermal output
- high voltage requirements, if the fuel cell system is to be connected directly to a high voltage electrical system electrical interconnection to the grid independent electrical loads

- electrical interconnection to the grid independent electrical loads
- extended or lengthy electrical and thermal connection interfaces (long interfaces increase installation costs)
- special piping material needs, site specific requirements
- special thermal equipment (absorption chilling equipment to supplement a continuous cooling need)
- dual fuel input capabilities
- complex site conditions and utilities interference
- indoor installations, a ventilation system is a requirement for indoor installations.

A typical fuel cell installation would involve a flat site with minimal site preparation required. An existing concrete pad in close proximity to the electrical and thermal source would create an ideal site for the equipment placement. The typical items listed above are necessary for a PC25C installation.

For a typical PC25C installation, the required length to reach an appropriate electrical interconnection and the thermal interface should be 100 ft or less. The average cost for a typical installation excluding any geographic cost index adjustments for labor should be in the \$90,000 to \$100,000 range. Any nontypical or auxiliary equipment will be in addition to the base installation cost.

The installation costs for some of the DOD fleet have been recorded and tabulated to allow review of installation options, interface requirements, and installation cost. These initial fuel cell systems cost an average of \$110,109 with a minimum cost of \$83,729 and a maximum cost of \$199,388.

3.4 Installation Recommendations

The *FCTec* was unique due to the indoor installation and close proximity to the electrical and thermal connections. The *CTC* PC25C installation cost of \$67,989 was significantly lower than standard typical costs because of excellent project management, close collaboration between the trades involved, and short utility service requirements.

There are many options available to minimize the cost of a fuel cell installation. The following are offered as cost saving guidelines to aid in the installation process:

- Use reliable experienced local contractors.
- Keep electrical and thermal utility interfaces to a minimum.
- Use optimum site location planning (locate to the most favorable site for the electrical and thermal needs within the facility).

- Maintain a compressed installation schedule to complete all trades at the same time to avoid inefficient dead time and overlap.
- Contact an experienced local rigging company and conduct a site visit to properly plan the placement procedure.
- Use the recovered thermal heat on a continuous basis (the higher the thermal use, the better the economic payback of the system).

4.0 Summary of Completed Tests

Seven tests were performed by *CTC* on the PC25C. Several of the tests required re-evaluation and re-testing to assure proper results. Two of the originally scheduled tests were not performed because of changes in scope of UTC Fuel Cells and ERDC/CERL. The development of a web based FTP site allowed for the quick transfer of large test data files to appropriate customers. The test data has been transmitted to both UTC Fuel Cells and ERDC/CERL via the *FCTec* FTP site. Customer information and data will not be presented in this report to protect client confidentiality.

4.1 Reference Natural Gas Testing

The purpose of Reference Natural Gas testing was to establish a database of power plant parameters that represent operations in a standard configuration for use in comparison to subsequent testing using alternative fuels and/or enhanced configurations.

The power plant was operated on utility natural gas in the grid connect mode with no customer heat recovery, for all test runs. The tests were established and designated by net power output levels to include idle mode, 50 kW, 100 kW, 125 kW, 150 kW, 175 kW, and 200 kW. The power plant systems were set up and configured for normal operation per UTC Fuel Cells PC25C operations manual.

CTC and UTC Fuel Cells reviewed all data captured for each power level following the completion of this test series. All pertinent measured, monitored, and computed parameters from the *FCTec* data acquisition system and the PC25C's existing data acquisition system were recorded and stored for each test run. Specific data samples captured for this test series included:

- Gas analysis (CO_2 , CO , CH_4 , N_2) of the reformer process exit
- Anode inlet and exit gas analysis (CO_2 , CO , CH_4 , N_2)
- Burner exhaust oxygen concentration
- Cathode exit oxygen concentration

- Cell stack assembly Cell Stack Assembly (CSA) cross pressure (anode inlet to cathode inlet)
- Glycol inlet and exit temperatures of cooling module
- Ambient temperature of cooling module area
- Exiting air temperature from cooling module fans
- Cooling module on/off status
- Feed water on/off status.

Using this data, UTC Fuel Cells was able to monitor the operational methods of the power plant. The 19 tube reformer, in this revised model, was the first to be tested in this fashion. The testing revealed some interesting parameters that required adjustments to the system. The reformer uses steam in its reaction of converting methane, CH_4 into H_2 . This conversion requires a specific steam to carbon ratio to operate at peak efficiency. A test to authenticate the amount of steam converted was added to validate the ratio and to make adjustments as required. Steam ratio adjustments were made to improve the power plant performance.

4.2 Special Fuels Testing

The objective of this test was to evaluate fuel cell performance when natural gas fuels containing high levels of Nitrogen gas (N_2) contaminants are used. Nitrogen, contained in natural gas is converted into ammonia gas (NH_3), which is known to reduce fuel cell life and adversely affect fuel cell operating performance. The data collected under this test provided quantifiable information regarding the amount of ammonia formed and reacted as a result of various N_2 gas quantities and cell stack load conditions.

The PC25C operated on utility natural gas in the grid connect mode with no customer heat recovery, for all test runs. During this test, N_2 gas was injected directly into the natural gas supply downstream of the FCTec fuel flow meter. Tests were performed at 0, 5, 10, and 15 percent N_2 injection into the fuel for idle, 100 kW, and 200 kW electrical loads. Data were collected at each N_2 /kW combination to assess the effects of both N_2 concentration and electrical load on ammonia production and cell stack reaction. The power plant systems were set up and configured for normal operation per the PC25C's operations manual.

All pertinent measured, monitored, and computed parameters from the FCTec data acquisition system and the PC25C's existing data acquisition system were recorded and stored for each test run. The primary parameters, which are of interest during this test, include the following:

- percentage of N_2 in the fuel supply

- N₂ flow rate
- N₂ pressure
- electrical load
- NH₃ concentration at cell stack inlet
- NH₃ concentration at cell stack exit.

Initially the testing was performed using a test method that incorrectly removed any ammonia that may have been in the sample. This was verified after performing a second and third test whereby modifying the sample train to assure that any ammonia present is captured and evaluated.

All other data available via *FCtec* data acquisition system and through the existing PC25C data acquisition system, was also collected to ensure that a complete record of both the initial setup and actual operating conditions during the test are recorded.

4.3 Heat Recovery Testing

The purpose of heat recovery testing was to validate the useful heat recovery capability from the PC25C low-grade and high-grade heat exchangers (HEX-880 and HEX 490).

The power plant was operated on utility natural gas in the grid connect mode for all test runs. The test operation was established by maintaining a constant return temperature within the customer's coolant system, while varying the coolant flow rate. One hour was allotted to allow the system to become stable following an adjustment to either the temperature or flow rates of the coolant. Two hours were allotted to allow for power level adjustments. Three modes of testing were performed to validate various customers' usage of the heat recovery capability from the PC25C. Each mode was tested at 100 kW and 200 kW power levels.

4.3.1 Mapping of High-Grade Heat Exchanger (HEX 490)

Water was used as the coolant for both PC25C and customer side during this test. The customer return temperature was varied from 100 °F to 250 °F in increments of 50 °F. The coolant flow rates for each temperature were varied from 10 gpm to 70 gpm in increments of 20 gpm.

4.3.2 Mapping of Low-Grade Heat Exchanger (HEX 880) with Water/Glycol Coolant when High-Grade Heat Exchanger (HEX 490) is in use

A water and glycol mixture was used as the plant side coolant in the low-grade system during this test. The high-grade heat recovery was operated at a fixed nominal capacity with water as the coolant medium. During this test, the customers low-grade return temperature was varied from 60 °F to 160 °F in increments of 20 °F. The coolant flow rates for each temperature was varied as specified in Table A3.

Table A3. Task 211, hex 880 test parameters, water/glycol – high grade in use.

Customer Side Return Temp (°F)	Customer Side Flow Rate (gpm)				
60	10	15			
80	10	15			
100	10	15	20	25	
120	10	15	25	45	90
140	10	15	25	45	90
160	10	15	25	45	90

4.3.3 Mapping of Low-Grade Heat Exchanger (HEX 880) with Water/Glycol Coolant when High-Grade Heat Exchanger (HEX 490) Is Not in Use

A water and glycol mixture was used as the plant side coolant in the low-grade system during this test. During this test, the customers low-grade return temperature was varied from 60 to 160°F in increments of 20 °F. The coolant flow rates for each temperature were varied as specified in Table A4.

Table A4. Task 211, hex 880 test parameters, water/glycol – high grade not in use.

Customer Side Return Temp (°F)	Customer Side Flow Rate (gpm)				
60	10	15			
80	10	15			
100	15	25	45	90	
120	15	25	45	90	
140	15	25	45	90	
160	15	25	45	90	

4.4 PCS and ECS Ventilation Testing

The purpose of PCS (Power Conditioning System) and ECS (Electronic Control System) ventilation testing was to determine the temperature distribution within the ventilation compartment. Air-cooling within the PCS/ECS compart-

ment was evaluated. The PC25C was operated on utility natural gas in grid connect mode. During this test, thermocouples were placed in the PCS/ECS compartment to acquire temperature data. The temperature data were captured and analyzed for test runs at idle and rated power level at 0.85 power factor.

In addition to the data collected from the thermocouples, all pertinent measured, monitored, and computed parameters from the *FCTec* data acquisition system and the PC25C data were recorded and stored for each test. No high temperature locations were identified that would require modifications to the compartment or alternate ventilation configurations.

4.5 Grid Independent Testing

4.5.1 Transient Response

The purpose of Grid Independent Testing was to gather data delineating PC25C capabilities and electrical output characteristics under changing electrical load conditions, primarily in a grid independent mode. For this test, the power plant fuel was natural gas and no heat recovery was used. Electrical loading was applied through a combination of resistive and motor loads. These electrical load banks were dedicated, isolated units that allowed for maximum flexibility of testing. Several sizes of electric motors between 5 hp and 50 hp supplied motor loading with both high-inertia and HVAC-type mechanical shaft loading including fan and pump loads. Several factors of power plant response were monitored. These included measures of voltage stability, power quality, and the capability of the plant to deliver the required power through transient load changes. Also, response to short circuit fault conditions and the ability to energize the load when transferring from grid connected to grid independent were tested. Grid Independent Testing was broken down into the following five test modes:

- overload test
- grid connect cycle to grid independent
- power quality
- short circuit.

The test modes along with the additional testing parameters completed under this scope are discussed below:

4.5.2 Transient Response (Motor Starting Loads)

This exercise tested the capability of the power plant to handle transient power demands created by induction motor startups. A typical PC25C installation in-

cluded an electrical load consisting of a combination of resistive and inductive components. For this model, the inductive portion of the load consisted of high-inertia/motor loads (dynamometer) and HVAC motor loads including fans and pumps. Starting motor loads can be a severe test of a power system with initial inrush currents sometimes exceeding 7 times normal motor full-load current ratings.

This test used combinations of both the resistive and motor load banks in a grid independent mode. The test was executed in multiple stages. In each trial, the power plant was subject to a nominal steady-state electrical load (combinations of resistive and inductive loads). Various motor loads ranging between 5 hp and 50 hp were added to the fuel cell power requirement, and the power plant response was monitored. The motors were connected to various systems including centrifugal fans and pumps. Execution of this test included use of both across the line and soft-start controllers. Before, during, and after each load addition test, system voltage, current, wattage, and power quality were recorded along with the nominal ratings of the loads.

Five transient tests were performed on the PC25C. The PC25C was operated in grid independent mode and configured with a base load for each test. Resistive and inductive loads were applied individually in steps to the base load. The duration of each load step was ten (10) seconds. The step load then was removed and the base load applied for another ten seconds prior to the next step load. Data were captured at high speed for a duration of twenty (20) seconds for each step load (5 seconds at base prior to load step + 10 seconds of applied load + 5 seconds after step removed). Several of the step loads caused an overload on the PC25C and subsequently forced either an idle state or a shutdown.

4.5.2 Overload Test

The PC25C's ability to handle overloads was tested during this exercise. Present published specifications on the power plant list its steady-state capacity at 200 kW with overload capabilities up to 5 seconds at 240 kW. For this test, the PC25C was configured for grid independent operation with no heat recovery. A resistive load bank was used as the electrical loading device. Nominal loading levels and system response were recorded, along with specific output voltage, current, wattage, and transient voltage/current response, for each test.

Two overload test formats were performed on the PC25C. The first test format consisted of applying overload steps for 1-, 2-, 3-, 4-, and 5-second durations to a base load of 200 kW. The cumulative resistive load steps were applied to the PC25C output until either an overload condition was reached (PC25C goes to idle

or shutdown) or all steps were successful. Data were captured at high speed for each step load at selected test duration's.

The second test format consisted of starting with the highest power level from the previous overload test that was able to operate for a maximum 4 second duration. This overload condition was tested to verify that a steady state continuous power condition could be achieved for a 10-second duration. The overload amount was reduced by 5 kW steps as needed to obtain the overload steady state continuous operating condition of the PC25C.

4.6 Dual Fuel Testing

Dual fuel testing was to be performed on the PC25C to evaluate the adaptability of the power plant during conversion from one input fuel stream to another. This testing documented the applicability of PC25C in emergency power applications. This testing was also necessary to gain AGA certification for the PC25C while operating on liquid propane (LP) fuel.

This testing has been postponed by UTC Fuel Cells due to development of the new reformer catalysts. CTC's activities in support of performing this test series were completed prior to receiving UTC Fuel Cells postponement of propane testing. A temporary propane system was installed and development of the test plan was completed. This test may be included in future testing of the PC25C. The availability of two input fuel streams, from separate sources, will allow PC25C to be designated as back-up emergency power providers. A dual fuel PC25C will provide increased system reliability.

4.7 Water Recovery Testing – Air Cooling Module Performance

This test has been discontinued in favor of performing extended baseline tests. The objective of Water Recovery Testing will be to characterize and validate the new high performance air cooling module and provide data to establish a set of limits within which the power plant can recover sufficient water required for operation. This test is anticipated to be completed during year three of this program. CTC and UTC Fuel Cells completed drafting of the preliminary test plans.

4.8 Water Quality Testing

The objective of water testing was to assess the water quality within the PC25C during operation. Fuel cell reliability and long term operation is often dependent on water quality. Previous fuel cell stack failures have been attributed to

poor water quality causing deposit build-up at essential cooling locations throughout the fuel cell. Improvements in input water quality and on-board water conditioning systems will provide enhanced system reliability.

The water quality of the fuel cell feed water (HV453), the TMS Loop (HV431), the on-board water storage tank, and the make-up water were sampled at a minimum of 48-hr intervals during the operation of the PC25C. Water samples from these locations were taken from inspection ports integrated into the system. Make up water to the power plant was taken from the deionized water system supply at the *FCTec*.

Samples were analyzed to document pH, conductivity, dissolved oxygen, and turbidity. Water temperature, power levels, and ambient air temperatures were measured and documented at the time of each sample event. Water quality test logs and charts were generated to trend each parameter.

Monthly, samples were collected and analyzed using laboratory equipment and the results compared to the analyses gathered at the power plant. This was done to assess the adequacy of the field methods for generating acceptable results. Laboratory analysis was also performed to collect information on Total Suspended Solids, Total Dissolved Solids, silica, Standard Plate Count, Total Organic Carbon, Metals (iron, copper, calcium, magnesium, and sodium) and ions (chloride, sulfate, nitrite, nitrate, and phosphate) during operation and over an extended period.

4.9 Emissions Sampling

Exhaust emission sampling was performed on the PC25C during the Baseline Power Plant Evaluation. This test was performed to verify emission levels of the PC25C operating on natural gas. The measured values allowed for comparison to historical PC25C emission data.

The emission output from the power plant was monitored and tested during operation with 100 percent utility natural gas. The power plant was operated in the grid-connect mode with no customer heat recovery, at 100 kW and 200 kW power levels.

The test results were documented to allow for future comparison of fuel cell emissions. The test was performed using Continuous Emissions Monitoring (CEM) equipment to monitor carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOC), total hydrocarbons (THC), and sample temperatures. Excess oxygen (O₂) was also measured at the Power Plant exhaust during

the emission tests. The emission tests compared the input, ambient air quality information with that measured from the fuel cell exhaust.

At least three 1-hr tests were performed at each power level. All equipment was calibrated using standard gases prior to each test. Software was used to capture data from each instrument during calibration and testing, and an average concentration was generated. All equipment was checked using standard gases after each 1-hr test to verify that the equipment operated correctly during testing. If any instrument showed drift during the data collection, the test was repeated.

5.0 Lessons Learned

Provided below are problems that were encountered during the first 2 years of this program that caused either modifications to the test schedule or contributed to unplanned costs. Where appropriate, lessons learned from these issues are presented.

5.1 PC25C PAFC Power Plant Delivery

The planned delivery date of the PC25C to FCTec was April 1, 1999. The power plant's actual delivery date to FCTec was 11 October 1999. Three (3) revised delivery dates were provided before the power plant actually arrived. A total of five project schedule modifications were required to address the delays of the delivery of the power plant. In addition, CTC had to reduce staffing of the fuel cell team until the power plant was installed and testing was able to start. The delays in delivery of the power plant resulted from issues that arose during the fabrication and testing at the manufacturer's site of several of the power plant systems.

Resolution of the delivery issues was outside of CTC's control. CTC in cooperation with UTC Fuel Cells and ERDC/CERL did draft a project schedule, which anticipated the delivery date, installation completion date and the planned start date for testing. However, the manufacturing complexities of the PC25C were not incorporated within this schedule.

5.1.1 Lessons Learned

Future fuel cell testing programs within FCTec, when appropriate, will address the manufacturer's fabrication and test schedule milestones within the program test schedule. This information may not help with the actual delivery date of the unit but it will identify the actions that need to be completed prior to FCTec re-

ceiving the unit for testing. This approach may assist with adding some contingency to the schedule.

5.2 Design Drawings for the In-door Ventilation System

CTC's initial approach was to fabricate and install the in-door ventilation system for the PC25C. This approach was decided after *CTC* and ERDC/CERL visited UTC Fuel Cells and reviewed the in-door ventilation system that UTC Fuel Cells was currently using for the PC25C units within their testing facility. UTC Fuel Cells did indicate that a modification to the in-door ventilation design was ongoing and that *CTC* would receive the design drawings once available. *CTC* used the information gained from this site visit to support the site preparation schedule and cost estimate.

The revised drawings provided by UTC Fuel Cells revealed that the fabrication and installation complexity of the new in-door ventilation system had significantly increased over UTC Fuel Cells earlier design. *CTC*'s in-house staff could no longer support the fabrication and installation support needed for the new in-door ventilation system.

Therefore, a qualified Heating, Ventilating, Air Conditioning (HVAC) subcontractor was used to fabricate and install the new in-door system. This change resulted in schedule delays and cost increases within the site preparation task.

5.2.1 Lessons Learned

Future fuel cell testing programs within *FCTec*, when appropriate, should consider the following approach concerning the installation of supporting fuel cell systems.

Work directly with the design company to obtain detailed design drawings and/or an engineering estimate of scope and cost of the supporting systems.

5.3 Thermal Load Bank System

The final cost of the design, assembly, test and delivery of thermal load bank (TLB) was approximately 2.5 times greater than the preliminary cost estimate. A sub-contractor in support of the preliminary design details developed by *CTC* and ERDC/CERL provided the initial estimated cost for this system. Several new enhancements/requirements (stainless steel piping, sensors, control devices,

and safety items) were added to the original design, which impacted this increase.

CTC and ERDC/CERL enhanced the design requirement of the TLB. The added features of the TLB enhanced the capabilities of this system to be used not only for testing and validating fuel cell heat recovery systems but also to be used to support testing and validating of fuel cell stacks.

5.3.1 Lessons Learned

Future fuel cell testing programs within *FC_{Tec}*, when appropriate, should consider the following approaches for calculating cost estimates when final design details are not properly defined:

- Request available options in material, data acquisition and controls when receiving a budgetary number from a equipment/system manufacturer.
- Apply a safety factor (contingency %) to all in-house engineering estimates in support of special equipment that will be manufactured outside of *CTC*.

5.4 Test Data Review

All test data captured in support of the baseline and extended scope testing on the PC25C were transferred to the project FTP site for UTC Fuel Cells and ERDC/CERL review. The initial project schedule identified a 1-week period for UTC Fuel Cells to review the data and provide comments back to *CTC* regarding the test. Due to the large data files the actual data review process took 2 to 3 weeks to complete. Several times *CTC* had advanced to the next baseline test only to receive word from UTC Fuel Cells that the previous test would need to be repeated due to improper operating parameters that were identified from the data review and analysis phase.

5.5 Testing Issues

CTC installed in-line sensors in support of capturing process data during the test and validation of the PC25C. Problems were encountered that caused replacement of several of the sensors. The task of removing the bad sensors and replacing with new sensors did require ongoing testing to be delayed. The sensors that required replacements during the baseline testing phase of the PC25C were:

- nine (9) pressure sensors
- four (4) temperature sensors
- two (2) mass flow meters.

In addition, several components malfunctioned during the normal operation of the PC25C in support of the baseline testing that required *CTC* to shut the power plant down and delay testing. A list of the problems encountered during the testing phase are provided below:

- nitrogen fuel line leak inside the PC25C
- replacement of the four (4) cooling module motors
- replacement of the hand operated ball valve within the thermal management loop
- replacement of several capacitors within the inverter.

5.4.1 Lessons Learned

Future fuel cell testing program within *FCTec*, when appropriate, should consider the following approaches for defining the program test plan schedule when test data review is required to determine the status of the test and/or the operating conditions of the fuel cell system:

- Determine actual size of the data file(s) and appropriate format required for the review and analysis phase.
- Work directly with the fuel cell manufacturers to receive the estimated duration and estimate milestones for the completion of the review and analysis.
- Assemble the program test schedule with an option to either repeat the previous test or start the set-up for the next test following the data review and analysis phase.

5.5.1 Lessons Learned

Future fuel cell testing program within *FCTec* will incorporate planned shutdown periods. This planned shutdown should be scheduled at a minimum of every 12 working weeks when testing with a maximum duration of 1 week. It is anticipated that a planned shutdown will provide some contingency within the program test schedule.

5.6 Vibration Test System

The final cost of the acquisition of the Vibration Test System was approximately twice the preliminary cost estimate. One major enhancement/requirement was added to the original design in the period from initial cost estimate to actual procurement. The overall capacity of this system was increased from testing 3 kW fuel cell systems to testing 10 kW fuel cell systems. This enhancement required a larger vibration test system than had been planned.

CTC and ERDC/CERL enhanced the design requirement of this system in support of attracting the fuel cell developers of low power systems to *FCTec*.

5.6.1 Lessons Learned

Future equipment cost estimate activities within *FCTec* will evaluate the current and future needs of the fuel cell technology industry prior to determining estimated cost of planned equipment.

5.7 Environmental Chamber Test System

The total cost of the acquisition of the Environmental Chamber Test System was approximately 1.25 times greater than the preliminary cost estimate. One major enhancement/requirement was added to the original design in the period from initial cost estimate to actual procurement. The overall capacity of this system was increased from testing 3 kW fuel cell systems to testing 10 kW fuel cell systems. This enhancement required a larger Environmental Chamber Test System than had been planned.

CTC and ERDC/CERL enhanced the design requirement of this system in support of attracting the fuel cell developers of low power systems to *FCTec*.

5.7.1 Lessons Learned

Future equipment cost estimate activities within *FCTec* will evaluate the current and future needs of the fuel cell technology *FCTec* prior to determining estimated cost of planned equipment.

6.0 Summary

This report fulfills the requirements of the SOW paragraphs 2.9.1 and 2.9.2 FY98 and FY99 Final Report and documents the tasks performed by *CTC* for the first 2 years of NDCEE Task N.211, U.S. Army ERDC/CERL Fuel Cell Program.

As described within this report, all planned objectives for the first 2 years of this program have been successfully completed. The information presented within this report addresses all the activities completed by *CTC* with the cooperation of ERDC/CERL to achieve the following objectives:

- The design and construction of the DOD *FCTec* within the ETF facility at *CTC* including the acquisition and installation of testing equipment within the *FCTec* for the support of PC25C testing and evaluation

- The acquisition and installation of a PC25C with customized capabilities
- The completion of testing within the *FCTec* to support baseline and performance improvement objectives of the ERDC/CERL fuel cell program
- The acquisition and installation of testing equipment within the *FCTec* for smaller fuel cell power plant systems.

As a result of the program objectives, the ERDC/CERL has established a National Resource that can provide independent, unbiased testing and validation of fuel cell power plants for military and commercial applications. This test center (*FCTec*) provides the ERDC/CERL with the capability to significantly support the development and commercialization of fuel cell power plants.

The ERDC/CERL has established funding to continue year three of this program. Future activities planned are consistent with the EDRC/CERL Fuel Cell Program objectives and in general include:

- Enhance the design of the DOD *FCTec*.
- Continue the test and evaluation activities on the PC25C.
- Procure and install testing equipment to support the test and evaluation of alternative technology fuel cell systems.
- Promote the use of *FCTec* to the fuel cell developers.

Appendix B: BT001A Test Plan

Title: Test Plan FCTP46533
FPS Gas Composition for SN9194
Test BT001A

REV. LTR.	AUTHOR	RELEASE NO.	DATE
—	Steve Pixton / Scott Kenner	D01PG1717	11 Nov 2001

PRODUCT FILE ADDRESS: Test Plan BT001A Test Plan for SN9194 11-06-2001.doc			
POWER PLANT/PROGRAM	SYSTEM & TAG NO.	PART NO.	DOCUMENT NO.
PC25C			FCTP46533

	REVISION RECORD			

DASH NO. LTR	REL NO.	LTR	DESCRIPTION	DATE
	—		Preliminary Draft	29 Oct 01
	D01PG1717		CTC / UTC FUEL CELLS Revisions	11 Nov 01

Objective

HDS exit gas samples at various heater band and control thermocouple locations will be captured.

Samples of the inlet natural gas will be taken.

The sample contents will be used for the analysis of sulfur compounds.

Length of Test

8- 10 days, single shift

Materials Required

- 30 6-litre sampling canisters
- Laptop with LDT software.

Ports Location for the Gas Samples

The gas samples for the HDS outlet gas will be taken at port AP001 (HDS exit after the steam ejector) and AP003 (HDS exit before the steam ejector).

The gas sample for the inlet gas will be taken at any convenient inlet port.

Test Set-Up

Figure B1 depicts the test configuration. Three additional ILS HTR002 heater bands (numbers 4, 5, and 6 in the figure) are to be installed on the ILS; three of the six total heater bands will be active at any one time during testing.

TE001, TE010, and TE002 will each be used as the heater control thermocouple during portions of the test.

33 additional thermocouples are to be installed per UTC Fuel Cells drawing XFC19433.

Three ON/OFF set-points for HTR002 will be used:

10. 550/575 °F
11. 565/585 °F
12. 540/560 °F

Two power levels will be run:

13. 200 kW
14. 80 kW

One sample of the incoming natural gas is required at the start of each new week of testing.

Data Acquisition Parameters

Table B1. BT001A test, miscellaneous data acquisition parameters.

Outside Temp	Glycol Supply Temp	Glycol Return Temp
Hex800 Discharge Air Temp	Nitrogen Mass Flow	Propane Mass Flow
Nitrogen Pressure	Natural Gas Mass Flow	Nitrogen Temperature
Natural Gas Temperature	Propane Temperature	Natural Gas Pressure
Propane Pressure	Inside Temperature	AP401
AP402	AP403	AP404
AP405	Anode Inlet Pressure	Anode Exit Pressure
Cross Pressure		

Table B2. BT001A test, thermocouple data acquisition parameters.

TE0021A	TE0021B	TE0022A	TE0022B	TE0022C	TE0023A	TE0023B
TE0023C	TE0024A	TE0024B	TE0024C	TE0025A	TE0025B	TE0025C
TE0025E	TE0026A	TE0026B	TE0026C	TE0027A	TE0027B	TE0027C
TE0028A	TE0028B	TE0028C	TE0029A	TE0029B	TE0029C	TE0029E
TE0030A	TE0030B	TE0030C	TE0031A	TE0031B		

Table B3. BT001A test, radar data acquisition parameters.

RADAR ANALOG	RADAR CALCULATED	RADAR CONTROL
RADAR DI	RADAR DO	RADAR DO CYCLES
RADAR INVERTER	RADAR INV DIO	RADAR SEQUENCE

Test Program

- A) Table 1 summarizes the test points at which sampling will take place.
- B) For each test, label the canister tags as listed in Table 1. Each test condition will require 1, 2 or 3 samples, as indicated in the table, thus label the canister tags 1.1, 1.2, etc, through 16.2. When preparing the sample canisters for overnight shipment, fill out the chain-of-custody record. In the space indicated check the “normal” block for turn around time.

- C) Record the LDT and Data Acquisition parameters at 10-minute intervals during testing and as samples are taken.
- D) Testing begins at 80 kW, then increases to 200 kW per Table B1. The test order between 80 kW and 200 kW is not critical to the program so if other considerations require switching the power order it can be done. Stabilization time is critical to all points therefore after a power change a stabilization time of at least 8 hrs is required.
- E) The 'Control Temperature During Sample' column of Table B1 refers to TE001, TE010, or TE002, depending on which T/C is indicated to be the Control T/C for each test. To a greater or lesser extent, all of these temperatures cycle from a maximum value to a minimum value. Each sample is to be taken at either the maximum or the minimum in the temperature cycle, as indicated on the table.
- F) The baseline tests (nos. 1-4) will collect data at the baseline heater and T/C configuration of the power plant.
- G) To change the Control T/C Set Point Range, go to LDT Screen 125, and change the HDS HEATER CONTROL DEADBAND (L,U) to the values in Table B1.
- H) To activate alternate heater bands, FIRST TRIP CIRCUIT BREAKER CB11.
- I) **BECAUSE OF THE HIGH VOLTAGE (480 V), TEST THE HTR002 TERMINAL BLOCK WITH A VOLTMETER TO ENSURE THERE IS NO VOLTAGE.** Next, disconnect and reconnect the appropriate heater bands. This shall be performed by plugging in the three heaters that are to be used according to this test schedule. Reset CB11 and verify that there is voltage on the heater terminal block.
- J) **To change the Control Thermocouple, FIRST OVERRIDE TE002 TO 550 DEGREES ON LDT SCREEN 99.** Then, swap the T/C leads at the T/C connector mounting bracket located on top of the ILS. Once the T/C's have been reconnected, clear the override. LDT will continue to read the TE002 position as the controlling temperature. **Since the actual control thermocouple will change during the testing it is essential to maintain a log that documents which thermocouple (TE001, TE010 and TE002) is being read on what channel to avoid confusion during data reduction.**
- K) **WHEN PROGRESSING FROM THE BASELINE TEST TO TEST A, FROM A TO B, AND AGAIN FROM B TO C, THE ILS TEMPERATURES MUST BE ALLOWED TO STABILIZE FOR AT LEAST 8 HRS.**
- L) At the conclusion of testing, reconnect TE002 as the control T/C, and reset the heater deadband settings to 550 and 575.

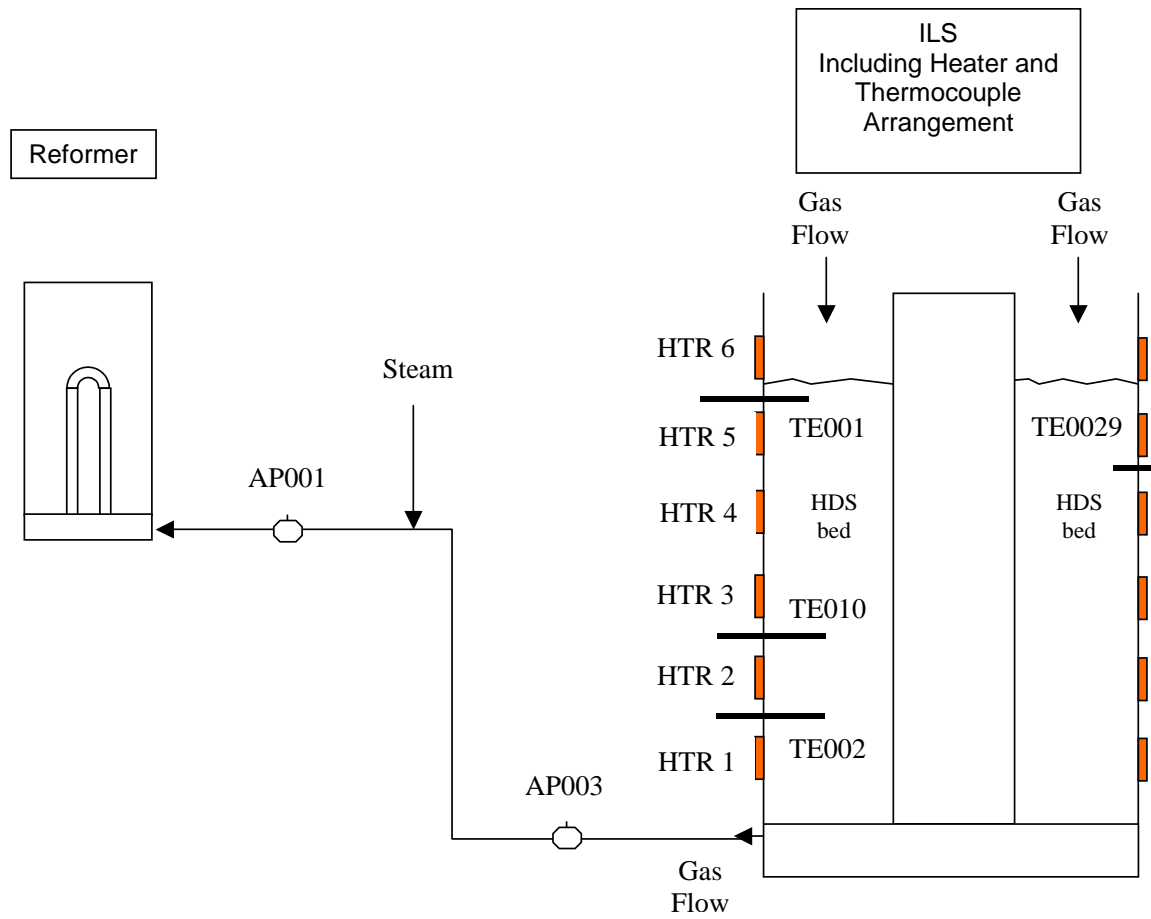


Figure B1. ILS, including heater and thermocouple arrangement.

Test No.	Test Description	Test Date	kW	Heater Number						Control Thermocouple location	Control T/C	Temp During Sample	Sample Location & Canister Tag No."			Comments
				#1	#2	#3	#4	#5	#6				HDS Exit AP003	Ref Inlet AP001	NG Inlet	
1	Baseline Test	12/10/01	80	✓	✓	✓				TE002	550 – 575	T max	1.1	1.2	1.3	Natural gas S level was 2.35 ppmV (89% THT); no S was detected at AP001 (<7 ppbV) or AP003 (<10 ppbV) Note that S samples at 200 kW were analyzed past the recommended 3-day hold time (did repeat 2 weeks later as Tests 1A though 4A)
2	↓	12/10/01	80	✓	✓	✓				TE002	°F	T min	2.1	2.2	—	
3		12/13/01	200	✓	✓	✓				TE002		T max	3.1	3.2	—	
4		12/13/01	200	✓	✓	✓				TE002		T min	4.1	4.2	—	
1A	Repeat of Baseline Test	12/27/01	80	✓	✓	✓				TE002	550 – 575	T max	1.1A	1.2A	—	No Sulfur was detected at AP001 (<7.5 ppbV) or AP003 (<10 ppbV) during either condition No Sulfur was detected at AP001 (<7.6 ppbV) or AP003 (<10 ppbV) during either T condition
2A	↓	12/27/01	80	✓	✓	✓				TE002	°F	T min	2.1A	2.2A	—	
3A		12/26/01	200	✓	✓	✓				TE002		T max	3.1A	3.2A	—	
4A		12/26/01	200	✓	✓	✓				TE002		T min	4.1A	4.2A	—	

5	Test A: High Htr, High Ctrl T/C	DNR	200	✓	✓	✓	TE001	565 – 585 °F	T max	—	—	—	Initial operation at 80 kW with TE001 as control could not achieve desired set points resulting in temperatures against the out side walls > 900 °F. Testing was aborted in favor of Test C. No S samples were taken
6	↓	DNR	200	✓	✓	✓	TE001		T min	—	—	—	
7		DNC	80	✓	✓	✓	TE001		T max	—	—	—	
8		DNC	80	✓	✓	✓	TE001		T min	—	—	—	
9	Test B: High Htr, Mid Ctrl T/C	DNR	80	✓	✓	✓	TE010	540 – 560 °F	T max	—	—	—	This test was not conducted after seeing results of Test A.
10	↓	DNR	80	✓	✓	✓	TE010		T min	—	—	—	
11		DNR	200	✓	✓	✓	TE010		T max	—	—	—	
12		DNR	200	✓	✓	✓	TE010		T min	—	—	—	
13	Test C: Mid Htr, Mid Ctrl T/C	12/18/01	200	✓	✓	✓	TE010	550–575 °F	T max	13.1	13.2	—	Based on Test A, increased HTR002 set points from 540-560 °F to 550-575 °F. TE001 ran cold. No S detected at either AP001 (<8 ppbV) or AP003 (<11 ppbV)
14	↓	12/18/01	200	✓	✓	✓	TE010		T min	14.1	14.2	—	
15		12/17/01	80	✓	✓	✓	TE010		T max	15.1	15.2	15.3	
16		12/17/01	80	✓	✓	✓	TE010		T min	16.1	16.2	—	

17	Test D: Mid Htr, Mid Ctrl T/C	12/19/01	200	✓	✓	✓	TE010	550–575 °F	T max	17.1	17.2	—	Changed HTR002 location to increase TE001; no real impact on temperature. No S detected at either AP001 (<8 ppbV) or AP003 (<11 ppbV)
18		12/19/01	200	✓	✓	✓	TE010		T min	18.1	18.2	—	
19		12/20/01	80	✓	✓	✓	TE010		T max	19.1	18.2	—	
20	↓ Test E: Mid Htr, High Outer Ctrl T/C	12/20/01	80	✓	✓	✓	TE010		T min	20.1	20.2	—	No S detected at either AP001 (<7 ppbV) or AP003 (<11 ppbV)
21		1/8/02	80	✓	✓	✓	TE0029A	640–660 °F	T max	21.1	21.2	21.3	Control T/C near outside wall for less T cycling. Natural gas S level was 1.75-1.95 ppmV (70% THT, 7% H2S, 8% t-BM) No S detected at AP001 (<7.3 ppbV) or AP003 (<11 ppbV)
22		DNR	80	✓	✓	✓	TE0029A		T min	—	—	—	
23		1/9/02	200	✓	✓	✓	TE0029A		T max	23.1	23.2	—	No S detected at AP001 (<8 ppbV) or AP003 (<10 ppbV) for either test.
24		1/9/02	200	✓	✓	✓	TE0029A		T min	24.1	24.2	—	

25	Test °F: Mid Htr, High Outer Ctrl T/C	1/10/02	200	✓	✓	✓	TE0029A	620–640 °F	T max	—	—	—	No sulfur sample taken. In previous tests 21-24 TE010 and TE002 ran a hotter than desired so set point was lowered
26		1/10/02	200	✓	✓	✓	TE0029A		T min	—	—	—	
27		1/11/02	80	✓	✓	✓	TE0029A		T max	—	—	—	
28		1/11/02	80	✓	✓	✓	TE0029A		T min	—	—	—	
29	Repeat of Baseline Test w/ GC install	2/4/02	80	✓	✓	✓	TE002	550 – 575 °F	T max	29.1 (W)	—	29.3	Natural gas S level was 0.87 ppmV (92% THT, 6% H2S). No S detected at AP003 (<6.8 ppbV) in either (W)et or (D)ry samples. Comparable GC also showed no sulfur.
30		2/4/02	80	✓	✓	✓	TE002		T min	29.1 (D) 30.1 (W) 30.1 (D)	—	—	
31		2/7/02	200	✓	✓	✓	TE002		T max	31.1 (W) 31.1 (D)	—	—	No S detected at AP003 (<6.8 ppbV) in either (W)et or (D)ry samples. Comparable GC also showed no sulfur.
32		2/7/02	200	✓	✓	✓	TE002		T min	32.1 (W) 32.1 (D)			Power plant operation at 200 kW was out of limits so GC sulfur data needs to be repeated
31A		2/25/02	200	✓	✓	✓	TE002		T max	31A1(W) 31A1 (D)	—	31A.3	

PHASE 2 TESTING w/ SCR CONTROL

33	Test G Repeat of Baseline Test w/ GC installed	2/27/02	200	✓	✓	✓			TE002	550 °F	SCR	—	—	33.3	P = 10, I = 0.0, D = 2.0
34	“	2/28/02	80	✓	✓	✓			TE002		SCR	—	—	—	P = 50, I = 0.1, D = 9.9

2/

35	Test H – Repeat of Test °F configur.	2/28/02	80			✓		✓	✓	TE0029A	630 °F	SCR	—	—	—	2/28/02 to 3/1/02
36	“	DNR	200			✓		✓	✓	TE0029A		SCR	—	—	—	3/1/02 to 3/3/02
35A	Test H – Repeat of Test °F configur.	3/1/02	80			✓		✓	✓	TE0029A	640 °F	SCR	—	—	—	P = 1.0, I = 0.1, D = 0.06
36A	“	3/4/02	200			✓		✓	✓	TE0029A	640 °F	SCR	—	—	—	As much as 9.4 ppbV EMS, <5 ppbV COS and occurrence of methyl mercaptan

37	Test I: <Mid htr, high outer ctrl T/C	3/5/02	200			✓	✓	✓		TE0029A	640 °F	SCR	—	—	37.3	Natural gas S level was 1.962 ppmV (82% THT, 7% t-BM, 5% H ₂ S. As much as 5.3 ppbV COS and EMS; occurrences of <5 ppbV H ₂ S, DMS and ethyl methyl mercaptan
38	“	3/6/02	80			✓	✓	✓		TE0029A	640 °F	SCR	—	—	—	As much as 8.1 ppbV H ₂ S, 5.7 ppbV COS and occurrences of <5 ppbV DMS and EMS
39	Test J: <Mid htr, high outer ctrl T/C	3/07/02	80				✓	✓	✓	TE0029A	640 °F	SCR	—	—	—	As much as 7.4 ppbV H ₂ S, 5.4 ppbV COS and occurrences of <5 ppbV EMS
40	“	3/8/02	200				✓	✓	✓	TE0029A	640 °F	SCR	—	—	—	H ₂ S as high as 6 ppbV, COS = 5.6 ppbV, methyl mercaptan = 7 ppbV and methyl ethyl sulfide < 5 ppbV Total Sulfur during any sample as high as 11.6 ppbV P = 40
31B	Repeat of Baseline from Phase 1	3/12/02	200	✓	✓	✓				TE002	550 – 575 °F	NA	—	—	—	< 5 ppbV of COS H ₂ S and MES (max of two compound together)
29B	Repeat of Baseline from Phase 1	3/13/02	80	✓	✓	✓				TE002	550 – 575 °F	NA	—	—	29B. 3	< 5 ppbV COS only at AP003. Natural gas S level was 2.145 ppmV (93% THT, 4% t-BM, 2% H ₂ S.

21A	Repeat of Test E from Phase 1	3/13/02	80			✓		✓	✓	TE0029A	640–660 °F	NA	—	—	—	< 5 ppbV COS only
23A	Repeat of Test E from Phase 1	3/14/02	200			✓		✓	✓	TE0029A	640–660 °F	NA	—	—	—	<5 ppbV COS ; documented <5ppbV peaks of DMS and THT
31C	Repeat of Baseline from Phase 1	3/15/02	200	✓	✓	✓				TE002	550 – 575 °F	NA	—	—	—	< 5 ppbV of COS, also documented < 5 ppbV peaks of ethyl mercaptan, DMS, and an unknown S compound
29C	Repeat of Baseline from Phase 1	3/19/02	80	✓	✓	✓				TE002	550 – 575 °F	NA	—	—	29C.3	Natural gas S level was 2.118 ppmV (94% THT, 2% DMS, 1% t-BM, no detected H2S (<19 ppbV).
35B	Repeat of Test H with P=40, I=.01	3/22/02	80			✓		✓	✓	TE0029A	640 °F	SCR	—	—	—	<5 ppbV COS ; documented <5ppbV peak of H2S P=40 (3/23-3/24) and P=60 (3/24-3/25)
35C	Repeat of Test H with P=80, I=.01	3/25/02	80			✓		✓	✓	TE0029A	640 °F	SCR	—	—	—	<5 ppbV COS w/ single occurrence of <5 ppbV of unknown S compound (retention time 4.3) P=40 between 3/23 and 3/24, P=60 between 3/24 and 3/25, P=80 on 3/26

36D	Repeat of Test H with P=80, I=.01	3/26/02	200			✓		✓	✓	TE0029A	640 °F	SCR	—	—	36D. 3	<5 ppbV COS w/ single occurrences of <5 ppbV of methyl mercaptan and unknown S compound (retention time 9.8) P=40 between 3/23 and 3/24, P=60 between 3/24 and 3/25, P=80 on 3/26 Natural gas S level was 3.1-3.3 ppmV (76% THT, 9% t-BM, 6% H ₂ S, detectable amounts of 7 other S compounds (DL=13 ppbV).
36D	Repeat of Test H with P=40, I=.01	3/27/02	200			✓		✓	✓	TE0029A	640 °F	SCR	—	—	—	
36D	P=200, I=0.5	3/27/02	200			✓		✓	✓	TE0029A	640 °F	SCR	—	—	—	No GC sulfur sampling
36D	P=200, I=1.0	3/28/02	200			✓		✓	✓	TE0029A	640 °F	SCR	—	—	—	No GC sulfur sampling
36D	P=400, I=1.0	3/28/02	200			✓		✓	✓	TE0029A	640 °F	SCR	—	—	—	No GC sulfur sampling
36D	P=400, I=2.0	3/29/02	200			✓		✓	✓	TE0029A	640 °F	SCR	—	—	—	No GC sulfur sampling
35E	P=100, I=0.25	3/31/02	80			✓		✓	✓	TE0029A	640 °F	SCR	—	—	—	
36E	P=100, I=0.25	4/3/02	200			✓		✓	✓	TE0029A	640 °F	SCR	—	—	36E. 3	GC data from 4/2/02 showed COS as much as 5.7 ppbV with no other peaks Natural gas S level was 3.1-3.3 ppmV (81% THT, 6% t-BM, 6% H ₂ S, detectable amounts of 7 other S compounds (DL=19 ppbV).

PHASE 3 TESTING w/ TE010 RELOCATED ¼" from OUTSIDE WALL with SCR HTR CONTROL

41	Test K – Repeat of Test °F heater config	4/17/02	80			✓		✓	✓	TE.010 Relocated	605 °F	SCR	—	—	41.3	P=100, I=0.25, D=0 for SCR control. Initial TE010 set point was 550 °F, then 620 °F and then 605 °F to match bed temps from Test 35 series. Natural gas S level was 2.9 ppmV (80% THT, 9% t-BM, 5% H ₂ S, detectable amounts of 7 other S compounds (DL=20 ppbV).
42	"	4/18/02	200			✓		✓	✓			SCR	—	—	—	
	EXTENDED TESTING	4/18/02-4/27/02	80 & 200			✓		✓	✓	TE.010 Relocated	605 °F	SCR	—	—	—	Evaluated impact of transients on control response of final configuration. P=100, I=0.25, D=0 for SCR control with set point on TE010 relocated to wall of 605 °F

**Canister Tag Number is a unique identifier to be placed on each gas sample canister.

DNR means Did Not Run test

DNC means Did Not Complete test

Appendix C: BT001B Test Plan

Title: Test Plan

Reference Natural Gas for SN9194

Test BT001B

REV. LTR.	AUTHOR	RELEASE NO.	DATE
—	LAS		21 Nov 2001

PRODUCT FILE ADDRESS: Test Plan BT001A.DOC			
POWER PLANT/PROGRAM	SYSTEM & TAG NO.	PART NO.	DOCUMENT NO.
PC25C			FCTP_BT001B_ PAGE 83 OF 5

REVISION RECORD

DASH NO. LTR	REL NO.	LTR	DESCRIPTION	DATE
		—	ORIGINAL ISSUE	29 Oct 01

Objective

Gas samples at various sample ports (Reformer Process exit, Anode Inlet, Anode Outlet, Cathode Exit, and Burner Exhaust) will be captured. The sample contents will be used for the analysis of light gases including Hydrogen, Carbon Dioxide, Oxygen, Nitrogen, methane, and Carbon Monoxide.

Length of Test

5 days, single shift

Materials Required

- GC equipped with gas sampling valve, columns (Hayes separation column and molecular sieve column), and computer control
- Hydrogen (8.5%) in helium carrier gas
- Dry Gas Meter
- 5L gas sample bags
- Compressed gases (Hydrogen, Nitrogen, Oxygen, Carbon Dioxide, Carbon monoxide, methane)
- Laptop with LDT software.

Port Location for Sampling

Reformer Process Exit (CO₂, CO, CH₄, N₂, H₂, & O₂)

Anode Inlet (CO₂, CO, CH₄, N₂, H₂, & O₂)

Anode Exit (CO₂, CO, CH₄, N₂, H₂, & O₂)

Cathode Exit (CO₂, CO, CH₄, N₂, H₂, & O₂)

Burner Exhaust (CO₂, CO, CH₄, N₂, H₂, & O₂)

Test Setup

Sampling will be conducted at Idle and at 200 kW, 175 kW, 150 kW, 125 kW, 100 kW, and 50 kW Power Levels.

Test Program

Reference Natural Gas Test BT001B

- 1.0 Pre-test Start Up Review (No Heat Recovery)
 - 1.1 Fuel Cell in Remote Operation
 - 1.2 Manual Disconnect Switch, (GI Load) Closed, MDS003
 - 1.3 Manual Disconnect Switch, (GC Load) Closed, MDS001
 - 1.4 Grid Connected MCB Closed, MCB002
 - 1.5 Grid Independent MCB Closed, MCB001
 - 1.6 Cooling Module Operational
 - 1.7 Thermal Flow pump Off, PMP 410 & VFD 413
 - 1.8 Low Grade Heat valves Closed, TLB 412
 - 1.9 High Grade Heat valves Closed, TLB 422 & TLB 423
 - 1.10 Thermal Load Bank crossover valves Closed, TLB 420 & TLB 421
 - 1.11 Chilled Water Supply Valve Closed, TLB 425, & TLB 411
 - 1.12 Nitrogen Injection Valve Closed, FPB 758
- 2.0 Verify Fuel Cell is operating on Natural Gas
- 3.0 Verify Fuel Cell at the appropriate Power Level for 2 hrs
- 4.0 Begin Recording Fuel Cell RADAR Data using a sample rate of 5 minutes.
- 5.0 Begin Recording Misc. Data for 1 hr using a sample rate of 1 minute unless noted otherwise.
 - 5.1 Cooling Module Information from *CTC* Sensors
 - 5.1.1 Fluid Flow Temperature In
 - 5.1.2 Fluid Flow Temperature Out
 - 5.1.3 Outside Ambient Air Temperature
 - 5.1.4 Inside Ambient Air Temperature
 - 5.1.5 Discharge Air Temperature
 - 5.2 Cell Stack Assembly (CSA) cross pressure from sensors
 - 5.2.1 PT3000
 - 5.2.2 PT3001
 - 5.3 Thermal Management System Parameters
 - 5.3.1 AP401
 - 5.3.2 AP402
 - 5.3.3 AP403
 - 5.3.4 AP404
 - 5.3.5 AP405
 - 5.4 Natural Gas Temperature and Flow from *CTC* Sensors
- 6.0 Sample Gas Analysis at each sample location (5 sites) during 1-hr test
- 7.0 Capture a RADAR snapshot of all steady-state values and set points
- 8.0 Stop recording data after 1 hr test or until gas analysis is completed
- 9.0 Adjust power level to the next net power output setting

- 10.0 Wait 2 hrs
- 11.0 Verify that the required Fuel Cell Power Level has been maintained for 2 hrs and repeat steps 1 through 11 until all testing is completed.

Data Acquisition Parameters

Table C1. Miscellaneous data acquisition parameters.

Outside Temp	Glycol Supply Temp	Glycol Return Temp
Hex800 Discharge Air Temp	Nitrogen Mass Flow	Propane Mass Flow
Nitrogen Pressure	Natural Gas Mass Flow	Nitrogen Temperature
Natural Gas Temperature	Propane Temperature	Natural Gas Pressure
Propane Pressure	Inside Temperature	AP401 Pressure
AP402 Pressure	AP403 Pressure	AP404 Pressure
AP405 Pressure	Anode Inlet Pressure	Anode Exit Pressure
Cross Pressure		

Table C2. Thermocouple data acquisition parameters.

TE0021A	TE0021B	TE0022A	TE0022B	TE0022C	TE0023A	TE0023B
TE0023C	TE0024A	TE0024B	TE0024C	TE0025A	TE0025B	TE0025C
TE0025E	TE0026A	TE0026B	TE0026C	TE0027A	TE0027B	TE0027C
TE0028A	TE0028B	TE0028C	TE0029A	TE0029B	TE0029C	TE0029E
TE0030A	TE0030B	TE0030C	TE0031A	TE0031B	TE0014A	TE0014B

Table C3. Radar data acquisition parameters.

Radar Analog	Radar Calculated	Radar Control
Radar Di	Radar Do	Radar Do Cycles
Radar Inverter	Radar Inv Dio	Radar Sequence

Appendix D: BT001C Test Plan

STACK EMISSION TESTING

- 1.0 Daily Start Up Review (No Heat Recovery).
 - 1.1 Fuel Cell in Remote Operation.
 - 1.2 Manual Disconnect Switch, (GI Load) Closed, MDS003.
 - 1.3 Manual Disconnect Switch, (GC Load) Closed, MDS001.
 - 1.4 Grid Connected MCB Closed MCB.
 - 1.5 Grid Independent MCB Closed, MCB001.
 - 1.6 Cooling Module Operational.
 - 1.7 Thermal Flow pump Off, PMP 410 & VFD 413.
 - 1.8 Low Grade Heat valves Closed, TLB 412
 - 1.9 High Grade Heat valves Closed, TLB 422 & TLB 423.
 - 1.10 High Grade Heat Crossover valves Closed, TLB 420 & TLB 421.
 - 1.11 Chilled Water Supply Valve Closed, TLB 425, & TLB 411.
 - 1.12 Nitrogen Injection Valve Closed, FPB 758.
- 2.0 Verify Fuel Cell is operating on Natural Gas.
- 3.0 Verify Fuel Cell power level is at 200 kW for 2 hrs.
- 4.0 Begin Recording Fuel Cell RADAR Data using a sample rate of 5 min.
- 5.0 Begin Recording Misc. Data for 1 hr at set power using a sample rate of 1 minute unless noted otherwise.
 - 5.1 Cooling Module Information from *CTC* Sensors
 - 5.1.1 Fluid Flow Temperature In.
 - 5.1.2 Fluid Flow Temperature Out.
 - 5.1.3 Outside Air Temperature.
 - 5.1.4 Inside Ambient Air Temperature.
 - 5.1.5 Discharge Air Temperature.
 - 5.2 Cell Stack Assembly (CSA) cross pressure from sensors
 - 5.2.1 PT3000
 - 5.2.2 PT3001
 - 5.3 Thermal Management System Parameters
 - 5.3.1 AP401
 - 5.3.2 AP402
 - 5.3.3 AP403
 - 5.3.4 AP404
 - 5.3.5 AP405
 - 5.4 Natural Gas Temperature, and Flow from *CTC* Sensors
- 6.0 Perform Emissions monitoring at each of two sites per the following methods:
 - 6.1 Process Exhaust Output Site, (Burner Exhaust)
 - 6.1.1 EPA Method 1 Sample and velocity transverses for stationary sources

- 6.1.2 EPA Method 2 Determination of stack gas velocity and volumetric flow rate (Type S pitot static tube).
- 6.1.3 EPA Method 3A Determination of Oxygen and Carbon Dioxide in emissions from stationary sources (Instrument Analyzer Procedure)
- 6.1.4 EPA Method 4 Determination of moisture content in stack gases
- 6.1.5 EPA Method 7E Determination of Nitrogen Oxide emissions form stationary sources (Instrument Analyzer Procedure)
- 6.1.6 EPA Method 10 Determination of Carbon Monoxide emissions form stationary sources.
- 6.1.7 EPA Method 25A Determination of Total Organic Concentration using a Flame Ionization Analyzer.
- 6.1.8 EPA Method 18 Measurement of Gaseous Organic Compound Emissions by Gas Chromatography
- 6.2 Ambient Air Sample
 - 6.2.1 EPA Method 1 Sample and velocity transverses for stationary sources
 - 6.2.2 EPA Method 2 Determination of stack gas velocity and volumetric flow rate (Type S pitot static tube).
 - 6.2.3 EPA Method 3A Determination of Oxygen and Carbon Dioxide in emissions from stationary sources (Instrument Analyzer Procedure)
 - 6.2.4 EPA Method 4 Determination of moisture content in stack gases
 - 6.2.5 EPA Method 7E Determination of Nitrogen Oxide emissions form stationary sources (Instrument Analyzer Procedure)
 - 6.2.6 EPA Method 10 Determination of Carbon Monoxide emissions form stationary sources.
 - 6.2.7 EPA Method 25A Determination of Total Organic Concentration using a Flame Ionization Analyzer.
 - 6.2.8 EPA Method 18 Measurement of Gaseous Organic Compound Emissions by Gas Chromatography
- 7.0 Perform Emissions monitoring at the following site:
 - 7.1 Cathode Outlet, AP120
 - 7.1.1 EPA Method 3A Determination of Oxygen in emissions from stationary sources (Instrument Analyzer Procedure)
- 8.0 The analysis shall run for 3-1 hr periods for each power level
- 9.0 Capture a RADAR snapshot of all steady-state values and set points after the completion of testing
- 10.0 Stop recording data at the end of test period.
- 11.0 Decrease power level by 100 kW net power output.
- 12.0 Wait 2 hrs
- 13.0 Verify that fuel cell is at set power for 2 hrs.
- 14.0 Go to step 4 if power level is equal to 100 kW.
- 15.0 End test, reset power plant to the default operating condition.

Appendix E: BT003 Test Plan

Heat Recovery

Mapping of High-Grade Heat Exchanger (HEX 490)

BT003A

- 16.0 Start Up Review (Heat Recovery).
 - 16.1 Fuel Cell in Remote Operation
 - 16.2 Manual Disconnect Switch, (GI Load) Open, MDS003
 - 16.3 Manual Disconnect Switch, (GC Load) Closed, MDS001
 - 16.4 Grid Connected MCB Closed, MCB002
 - 16.5 Grid Independent MCB Closed, MCB001
 - 16.6 Cooling Module Operational
 - 16.7 Thermal Flow pump Off, PMP 410 & VFD 413
 - 16.8 Low Grade Heat valves Closed, TLB 412
 - 16.9 High Grade Heat valves Closed, TLB 422 & TLB 423
 - 16.10 Thermal Load Bank crossover valves Closed, TLB 420&TLB 421
 - 16.11 Chilled Water Supply Valve Closed, TLB 425
 - 16.12 Nitrogen Injection Valve Closed, FPB 758
- 17.0 Verify Fuel Cell is operating on Natural Gas.
- 18.0 Verify Fuel Cell power level is at 200 kW for 2 hrs.
- 19.0 Open Chilled Water supply valve TLB 425
- 20.0 Open Flow Control Valve FCV 411 to 25% open
- 21.0 Verify CW Flow via visual flow indicator if attended operation
- 22.0 Verify Low Grade Valve, TLB 412 is Closed
- 23.0 Verify TLB 422 & TLB 423 are Closed
- 24.0 Open TLB Crossover Valves (HG mode) TLB 420 & TLB 421
- 25.0 Turn Thermal Flow Pump On, PMP 410 & VFD 413
- 26.0 Set VFD 413 speed (HZ) until FT 419 reads 10 gpm
- 27.0 Adjust Flow Control Valve FCV 411 until Customer Return Temperature TE 446 stabilizes @ 100 °F (up to 1 hr)
- 28.0 Begin Recording Fuel Cell RADAR Data using a sample rate of 5 min.
- 29.0 Begin Recording Misc. Data for 15 minutes using a sample rate of 1 minute unless noted otherwise.
 - 29.1 Cooling Module Information from CTC Sensors.
 - 29.1.1 Fluid Flow Temperature In.
 - 29.1.2 Fluid Flow Temperature Out.
 - 29.1.3 Outside Air Temperature.
 - 29.1.4 Inside Ambient Air Temperature.
 - 29.1.5 Discharge Air Temperature.
 - 29.2 Cell Stack Assembly (CSA) cross pressure from sensors.
 - 29.2.1 PT3000

- 29.2.2 PT3001
- 29.3 Thermal Management System Parameters.
 - 29.3.1 AP401
 - 29.3.2 AP402
 - 29.3.3 AP403
 - 29.3.4 AP404
 - 29.3.5 AP405
- 29.4 Natural Gas Temperature, and Flow from *CTC* Sensors.
- 30.0 Begin Recording Thermal Load Bank (TLB) Data for 15 minutes using a sample rate of 1 minute unless noted otherwise.

15.1 FCV-411 Position Command	15.10 LG Supply Temperature	15.19 Fill / Boost Pump
15.2 VFD-413 Speed Command	15.11 LG Return Temperature	15.20 TE443
15.3 LG Supply Pressure	15.12 HG Supply Temperature	15.21 TE444
15.4 LG Return Pressure	15.13 HG Return Temperature	15.22 TE445
15.5 LG Flow Rate	15.14 VFD Start Command	15.23 TE446
15.6 HG Supply Pressure	15.15 HG/LG Isolation Solenoid #1	15.24 PT447
15.7 HG Return Pressure	15.16 HG/LG Isolation Solenoid #2	15.25 PT448
15.8 HG Flow Rate	15.17 HG Chilled Water Solenoid	15.26 PT449
15.9 FCV-411 Position	15.18 LG Chilled Water Solenoid	15.27 PT450

- 31.0 After 15 minute test, Capture a RADAR snapshot of all steady-state values and setpoints
- 32.0 Stop recording Misc. & TLB data after 15 minute test
- 33.0 Adjust Flow Control Valve FCV 411 until Customer Return Temperature TE 446 stabilizes @ 50 °F greater than past setting (up to an hour)
- 34.0 Go to step 13.0 up to and including the 250 °F setting
- 35.0 Increase VFD 413 speed in HZ until FT 419 reads 20 gpm greater than past setting
- 36.0 Go to step 12.0 up to and including the 70 gpm setting
- 37.0 Decrease Fuel Cell Power Level by 100 kW
- 38.0 If power is less than 100 kW go to step 26.0
- 39.0 Verify Fuel Cell power level is at set power for 2 hrs.
- 40.0 Go to step 11.0
- 41.0 End test, reset power plant to the default operating condition.

Heat Recovery

Mapping of Low-Grade Heat Exchanger (HEX 880) with Water/Glycol Coolant when High-Grade Heat Exchanger (HEX 490) is in use

BT003A

- 1.0 Start Up Review (Heat Recovery).
 - 1.1 Fuel Cell in Remote Operation
 - 1.2 Manual Disconnect Switch, (GI Load) Open, MDS003
 - 1.3 Manual Disconnect Switch, (GC Load) Closed, MDS001
 - 1.4 Grid Connected MCB Closed, MCB002
 - 1.5 Grid Independent MCB Closed, MCB001
 - 1.6 Cooling Module Operational

- 1.7 Thermal Flow pump Off, PMP 410 & VFD 413
- 1.8 Low Grade Heat valves Closed, TLB 412
- 1.9 High Grade Heat valves Closed, TLB 422 & TLB 423
- 1.10 Thermal Load Bank crossover valves Closed, TLB 420&TLB 421
- 1.11 Chilled Water Supply Valve Closed, TLB 425
- 1.12 Nitrogen Injection Valve Closed, FPB 758
- 2.0 Verify Fuel Cell is operating on Natural Gas.
- 3.0 Verify Fuel Cell power level is at 200 kW for 2 hrs.
- 4.0 Open Chilled Water supply valve TLB 425
- 5.0 Open Flow Control Valve FCV 411 to 25% open
- 6.0 Verify CW Flow via visual flow indicator if attended operation
- 7.0 Open Low Grade Valve, TLB 412
- 8.0 Verify HOG 442 is 100% Open. Open TLB 422 & TLB 423 (Chilled Water to HEX 490 (HG))
- 9.0 Verify TLB Crossover Valves are Closed (LG mode), TLB 420 & TLB 421
- 10.0 Turn Thermal Flow Pump On, PMP 410 & VFD 413
- 11.0 Adjust Flow Control Valve FCV 411 until Customer Return Temperature (CRT) TE 444 approximates 60 °F
- 12.0 Set VFD 413 speed (HZ) until FT 405 reads the first Customer Flow Rate for the current Customer Return Temperature setting per Table E1 below. Adjustment of FCV 411 will be required to stabilize current CRT (TE 444) setting (up to an hour)
- 13.0 Begin Recording Fuel Cell RADAR Data using a sample rate of 5 min.
- 14.0 Begin Recording Misc. Data for 15 minutes using a sample rate of 1 minute unless noted otherwise.
 - 14.1 Cooling Module Information from CTC Sensors.
 - 14.1.1 Fluid Flow Temperature In.
 - 14.1.2 Fluid Flow Temperature Out.
 - 14.1.3 Outside Air Temperature.
 - 14.1.4 Inside Ambient Air Temperature.
 - 14.1.5 Discharge Air Temperature.
 - 14.2 Cell Stack Assembly (CSA) cross pressure from sensors.
 - 14.2.1 PT3000
 - 14.2.2 PT3001
 - 14.3 Thermal Management System Parameters.
 - 14.3.1 AP401
 - 14.3.2 AP402
 - 14.3.3 AP403
 - 14.3.4 AP404
 - 14.3.5 AP405
 - 14.4 Natural Gas Temperature, and Flow from CTC Sensors.

- 15.0 Begin Recording Thermal Load Bank (TLB) Data for 15 minutes using a sample rate of 1 minute unless noted otherwise.

15.1 FCV-411 Position Command	15.10 LG Supply Temperature	15.19 Fill / Boost Pump
15.2 VFD-413 Speed Command	15.11 LG Return Temperature	15.20 TE443
15.3 LG Supply Pressure	15.12 HG Supply Temperature	15.21 TE444
15.4 LG Return Pressure	15.13 HG Return Temperature	15.22 TE445
15.5 LG Flow Rate	15.14 VFD Start Command	15.23 TE446
15.6 HG Supply Pressure	15.15 HG/LG Isolation Solenoid #1	15.24 PT447
15.7 HG Return Pressure	15.16 HG/LG Isolation Solenoid #2	15.25 PT448
15.8 HG Flow Rate	15.17 HG Chilled Water Solenoid	15.26 PT449
15.9 FCV-411 Position	15.18 LG Chilled Water Solenoid	15.27 PT450

- 16.0 After 15 minute test, Capture a RADAR snapshot of all steady-state values and setpoints
- 17.0 Stop recording Misc. & TLB data after 15 minute test
- 18.0 Set VFD 413 speed (HZ) until FT 405 is set at the next Customer Side Flow Rate for the current Customer Side Return Temperature setting per Table E1 below. Adjustment of FCV 411 will be required to stabilize current CRT (TE 444) setting (up to an hour)
- 19.0 Go to step 13.0 until all Customer Side Flow Rates are completed for the current Customer Side Return Temperature
- 20.0 Adjust Flow Control Valve FCV 411 until Customer Return Temperature TE 444 is 20 °F greater than past setting
- 21.0 Go to step 12.0 up to and including the 160 °F setting
- 22.0 Decrease Fuel Cell Power Level by 100 kW
- 23.0 If power is less than 100 kW go to step 26.0
- 24.0 Verify Fuel Cell power level is at set power for 2 hrs
- 25.0 Go to step 11.0.
- 26.0 End test, reset power plant to the default operating condition.

Table E1. BT003 test, hex 880 test parameters, water/glycol – high grade in use.

Customer Side Return Temp (°F)	Customer Side Flow Rate (gpm)				
	5	10	15	N/A	N/A
60	5	10	15	N/A	N/A
80	5	10	15	N/A	N/A
100	5	10	15	20	25
120	5	15	25	45	90
140	5	15	25	45	90
160	10	15	25	45	90

Heat Recovery

Mapping of Low-Grade Heat Exchanger (HEX 880) with Water/Glycol Coolant when High-Grade Heat Exchanger (HEX 490) is not in use

BT003A

- 1.0 Start Up Review (Heat Recovery).
 - 1.1 Fuel Cell in Remote Operation
 - 1.2 Manual Disconnect Switch, (GI Load) Open, MDS003
 - 1.3 Manual Disconnect Switch, (GC Load) Closed, MDS001
 - 1.4 Grid Connected MCB Closed, MCB002
 - 1.5 Grid Independent MCB Closed, MCB001
 - 1.6 Cooling Module Operational
 - 1.7 Thermal Flow pump Off, PMP 410 & VFD 413
 - 1.8 Low Grade Heat valves Closed, TLB 412
 - 1.9 High Grade Heat valves Closed, TLB 422 & TLB 423
 - 1.10 Thermal Load Bank crossover valves Closed, TLB 420&TLB 421
 - 1.11 Chilled Water Supply Valve Closed, TLB 425
 - 1.12 Nitrogen Injection Valve Closed, FPB 758
- 2.0 Verify Fuel Cell is operating on Natural Gas.
- 3.0 Verify Fuel Cell power level is at 200 kW for 2 hrs.
- 4.0 Open Chilled Water supply valve TLB 425
- 5.0 Open Flow Control Valve FCV 411 to 25% open
- 6.0 Verify CW Flow via visual flow indicator if attended operation
- 7.0 Open Low Grade Valve, TLB 412
- 8.0 Verify TLB 422 & TLB 423 are Closed
- 9.0 Verify TLB Crossover Valves are Closed (LG mode), TLB 420 & TLB 421
- 10.0 Turn Thermal Flow Pump On, PMP 410 & VFD 413
- 11.0 Adjust Flow Control Valve FCV 411 until Customer Return Temperature (CRT) TE 444 approximates 60 °F
- 12.0 Set VFD 413 speed (HZ) until FT 405 reads the first Customer Flow Rate for the current Customer Return Temperature setting per Table below. Adjustment of FCV 411 will be required to stabilize current CRT (TE 444) setting (up to an hour)
- 13.0 Begin Recording Fuel Cell RADAR Data using a sample rate of 5 min.
- 14.0 Begin Recording Misc. Data for 15 minutes using a sample rate of 1 minute unless noted otherwise.
 - 14.1 Cooling Module Information from CTC Sensors.
 - 14.1.1 Fluid Flow Temperature In.
 - 14.1.2 Fluid Flow Temperature Out.
 - 14.1.3 Outside Air Temperature.
 - 14.1.4 Inside Ambient Air Temperature.
 - 14.1.5 Discharge Air Temperature.
 - 14.2 Cell Stack Assembly (CSA) cross pressure from sensors.
 - 14.2.1 PT3000
 - 14.2.2 PT3001
 - 14.3 Thermal Management System Parameters.
 - 14.3.1 AP401

14.3.2 AP402

14.3.3 AP403

14.3.4 AP404

14.3.5 AP405

14.4 Natural Gas Temperature, and Flow from *CTC* Sensors.

15.0 Begin Recording Thermal Load Bank (TLB) Data for 15 minutes using a sample rate of 1 minute unless noted otherwise.

15.1 FCV-411 Position Command	15.10 LG Supply Temperature	15.19 Fill / Boost Pump
15.2 VFD-413 Speed Command	15.11 LG Return Temperature	15.20 TE443
15.3 LG Supply Pressure	15.12 HG Supply Temperature	15.21 TE444
15.4 LG Return Pressure	15.13 HG Return Temperature	15.22 TE445
15.5 LG Flow Rate	15.14 VFD Start Command	15.23 TE446
15.6 HG Supply Pressure	15.15 HG/LG Isolation Solenoid #1	15.24 PT447
15.7 HG Return Pressure	15.16 HG/LG Isolation Solenoid #2	15.25 PT448
15.8 HG Flow Rate	15.17 HG Chilled Water Solenoid	15.26 PT449
15.9 FCV-411 Position	15.18 LG Chilled Water Solenoid	15.27 PT450

16.0 After 15 minute test, Capture a RADAR snapshot of all steady-state values and setpoints

17.0 Stop recording Misc. & TLB data after 15 minute test

18.0 Set VFD 413 speed (HZ) until FT 405 is set at the next Customer Side Flow Rate for the current Customer Side Return Temperature setting per Table E2 below. Adjustment of FCV 411 will be required to stabilize current CRT (TE 444) setting (up to an hour)

19.0 Go to step 13.0 until all Customer Side Flow Rates are completed for the current Customer Side Return Temperature

20.0 Adjust Flow Control Valve FCV 411 until Customer Return Temperature TE 444 is 20 °F greater than past setting

21.0 Go to step 12.0 up to and including the 160 °F setting

22.0 Decrease Fuel Cell Power Level by 100 kW

23.0 If power is less than 100 kW go to step 26.0

24.0 Verify Fuel Cell power level is at set power for 2 hours

25.0 Go to step 11.0.

26.0 End test, reset power plant to the default operating condition.

Table E2. BT003 test, hex 880 test parameters, water/glycol – high grade not in use

Customer Side Return Temp (°F)	Customer Side Flow Rate (gpm)			
	5	10	15	N/A
60	5	10	15	N/A
80	5	10	15	20
100	15	25	45	90
120	15	25	45	90
140	15	25	45	90
160	15	25	45	90

Appendix F: BT005A Test Plan

Outline

Five (5) total transient tests will be performed on the fuel cell power plant (FCPP). The FCPP will be operated in grid independent mode and configured with a base load for each test. Resistive and inductive loads will be applied individually in steps to the base load. The duration of each load step will be 10 seconds. The step load will then be removed and the base load will be applied for another ten seconds prior to the next step load. The sequence of adding and removing a step load to the base load will be performed as outlined in the five (5) tables provided within this test plan. Data will be captured at high speed for a duration of twenty (20) seconds for each step load (5 seconds at base prior to load step + 10 seconds of applied load + 5 seconds after step removed). It is anticipated that several of these step loads may cause an overload on the FCPP and that the FCPP will either transfer to idle or shutdown. Each of the five tests will end when either of the following event happenings: shutdown or idle condition or all steps are applied with no mishaps.

Daily Start Up / Pre-Test Review (No Heat Recovery)

- Fuel Cell in Local Operation
- Manual Disconnect Switch, (GI Load) Closed, MDS003
- Manual Disconnect Switch, (GC Load) Closed, MDS001
- Grid Connected MCB Closed, MCB002
- Grid Independent MCB Closed, MCB001
- Cooling Module Operational
- Thermal Flow pump Off, PMP 410 & VFD 413
- Low Grade Heat valves Closed, TLB 412
- High Grade Heat valves Closed, TLB 422 & TLB 423
- Thermal Load Bank crossover valves Closed, TLB 420 & TLB 421
- Chilled Water Supply Valve Closed, TLB 425
- Verify Nitrogen Injection Valve Closed, FPB 758
- Verify Fuel Cell is operating on Natural Gas
- Verify Fuel Cell is at desired power level.

Test Procedure

- 1.0 Verify Grid Independent loads off status.
- 2.0 Set up the desired Grid Independent test plan on CDAQ as outlined in tables 1 through 5. Testing sequence shall begin with test/table 1 and incremented up to test/table 5.
- 3.0 Configure CDAQ data recording at ½ second update rate for the miscellaneous & ELB data.
- 4.0 Set up portable high-speed data acquisition system to capture data at a sampling rate of **1000 samples/second** from the Resistive Load Bank (RLB) and Motor Load Bank (MLB).
- 5.0 Set up Dranetz 658 Disturbance Analyzer to record power quality data.
- 6.0 Connect PC to LDT port and select Grid Independent Load – disconnect.
- 7.0 Connect CTC's CDAQ (RADAR DAQ connection) cable to the LDT port.
- 8.0 **Initiate Test via CDAQ** – This sequence will begin the desired test as outlined in tables 1 through 5 within this test plan. The following data acquisition will also be initiated at the start of each test.
 - 8.1 UTC Fuel Cells RADAR data snapshot.
 - 8.2 Miscellaneous & ELB data acquisition (at ½ second update)
 - 8.3 High-speed data acquisition (at 1000 samples/second)
 - 8.4 Dranetz 658 Disturbance Analyzer data recording
- 9.0 Perform desired test as outlined in tables 1 through 5 within this test plan. This process will be automatically controlled via CDAQ. The following data acquisition shutdown will occur at the end of each test.
 - 9.1 UTC Fuel Cells RADAR data snapshot.
 - 9.2 Miscellaneous & ELB data acquisition
 - 9.3 High-speed data acquisition
 - 9.4 Dranetz 658 Disturbance Analyzer data recording
- 10.0 Return to Step 1.0 and perform next test. Five total test required (one per test/table)
- 11.0 End BT005A testing – reset power plant to the default operating condition.

Table F1. BT005A test, miscellaneous data acquisition parameters.

Fluid Flow Temperature In	Cross pressure	AP401
Fluid Flow Temperature Out	Inside Ambient Air Temperature	AP402
Outside Ambient Air Temperature	Discharge Air Temperature	AP403
		AP404
		AP405
		PT3000
		PT3001

Table F2. BT005A test, ELB data acquisition parameters status

20 hp PWM Line Side	50 hp SS Line Side	50 kW Resistor – A	Fan 4 – 5 hp
20 hp PWM Load Side	50 hp SS Load Side	50 kW Resistor – B	Pump – 15 hp
20 hp SS Line Side	50 hp SS Enabler	50 kW Resistor – C	

20 hp SS Load Side	5k W Resistor	50 kW Resistor – D	
20 hp SS Enabler	10 kW Resistor	Fan 1 – 5 hp	
20 hp SS Starter	20 kW Resistor – A	Fan 2 – 5 hp	
50 hp SS Starter	20 kW Resistor – B	Fan 3 – 5 hp	

Table F3. BT005A test, ELB data acquisition parameters values.

L1-N Voltage	L2-N Voltage	L3-N Voltage
RLB L1 Current	RLB L2 Current	RLB L3 Current
MLB KWattmeter		

Table F4. BT005A test, high speed data acquisition parameters.

MLB Phase 1 – Instant. Amps	RLB Phase 1 – RMS Amps	Phase 3 – L/N Instant. Volts
MLB Phase 2 – Instant. Amps	RLB Phase 2 – RMS Amps	Phase 1 – L/N RMS Volts
MLB Phase 3 – Instant. Amps	RLB Phase 3 – RMS Amps	Phase 2 – L/N RMS Volts
MLB kW	Phase 1 – L/N Instant. Volts	Phase 3 – L/N RMS Volts
Stack – DC Instant. volts	Phase 2 – L/N Instant. Volts	

Table F5. BT005A test/table 1 as tested format.

Base Load – 0 kW					
Steps	Load Step	Comments	Load Type	Duration (seconds)	Total Test Time (seconds)

Base Load – 0 kW					
Steps	Load Step	Comments	Load Type	Duration (seconds)	Total Test Time (seconds)
1	0	Base load	None	10	10
2	50 kW	50 kW total	Resistive	10	20
3	0	Base load	None	10	30
4	100 kW	100 kW total	Resistive	10	40
5	0	Base load	None	10	50
6	150 kW	150 kW total	Resistive	10	60
7	0	Base load	None	10	70
8	5 hp	Base load + hp Line to Line motor start	Inductive	10	80
9	0	Base load	None	10	90
10	10 hp	Base load + hp Line to Line motor starts Two motor combination	Inductive	10	100
11	0	Base load	None	10	110
12	15 hp	Base load + hp Line to Line motor start	Inductive	10	120
13	0	Base load	None	10	130
14	20 hp	Base load + hp Soft Start motor start	Inductive	10	140
15	0	Base load	None	10	150
16	20 hp	Base load + hp Line to Line motor start	Inductive	10	160
17	0	Base load	None	10	170
18	25 hp	Base load + hp Line to Line motor starts Three motor combination	Inductive	10	180
19	0	Base load	None	10	190
20	30 hp	Base load + hp Line to Line motor starts Four motor combination	Inductive	10	200
21	0	Base load	None	10	210
22	50 hp	Base load + hp Soft Start motor start	Inductive	10	220
23	0	Base load	None	10	230
End					

Table F6. BT005A test/table 2 as tested format.

Base Load – 50 kW					
Steps	Load Step	Comments	Load Type	Duration (seconds)	Total Test Time (seconds)
1	50 kW	Base load	Resistive	10	10
2	50 kW	100 kW total	Resistive	10	20
3	50 kW	Base load	Resistive	10	30
4	100 kW	150 kW total	Resistive	10	40
5	50 kW	Base load	Resistive	10	50
6	150 kW	200 kW total	Resistive	10	60
7	50 kW	Base load	Resistive	10	70
8	5 hp	Base load + hp Line to Line motor start	Inductive & Resistive	10	100
9	50 kW	Base load	Resistive	10	110
10	10 hp	Base load + hp Line to Line motor starts Two motor combination	Inductive & Resistive	10	120
11	50 kW	Base load	Resistive	10	130
12	15 hp	Base load + hp Line to Line motor start	Inductive & Resistive	10	140
13	50 kW	Base load	Resistive	10	150
14	20 hp	Base load + hp Soft Start motor start	Inductive & Resistive	10	160
15	50 kW	Base load	Resistive	10	170
16	20 hp	Base load + hp Line to Line motor start	Inductive & Resistive	10	180
17	50 kW	Base load	Resistive	10	190
18	25 hp	Base load + hp Line to Line motor starts Three motor combination	Inductive & Resistive	10	200
19	50 kW	Base load	Resistive	10	210
20	30 hp	Base load + hp Line to Line motor starts Four motor combination	Inductive & Resistive	10	220
21	50 kW	Base load	Resistive	10	230
22	50 hp	Base load + hp Soft Start motor start	Inductive & Resistive	10	240
23	50 kW	Base load	Resistive	10	250
24	0	0	0	10	260
End					

Table F7. BT005A test/table 3 as tested format.

Base Load – 100 kW					
Steps	Load Step	Comments	Load Type	Duration (seconds)	Total Test Time (seconds)
1	100 kW	Base load	Resistive	10	10
2	50 kW	150 kW total	Resistive	10	20
3	100 kW	Base load	Resistive	10	30
4	80 kW	180 kW total	Resistive	10	40
5	100 kW	Base load	Resistive	10	50
6	100 kW	200 kW total	Resistive	10	60
7	100 kW	Base load	Resistive	10	70
8	5 hp	Base load + hp Line to Line motor start	Inductive & Resistive	10	80
9	100 kW	Base load	Resistive	10	90
10	10 hp	Base load + hp Line to Line motor starts Two motor combination	Inductive & Resistive	10	100
11	100 kW	Base load	Resistive	10	110
12	15 hp	Base load + hp Line to Line motor start	Inductive & Resistive	10	120
13	100 kW	Base load	Resistive	10	130
14	20 hp	Base load + hp Soft Start motor start	Inductive & Resistive	10	140
15	100 kW	Base load	Resistive	10	150
16	20 hp	Base load + hp Line to Line motor start	Inductive & Resistive	10	160
17	100 kW	Base load	Resistive	10	170
18	25 hp	Base load + hp Line to Line motor starts Three motor combination	Inductive & Resistive	10	180
19	100 kW	Base load	Resistive	10	190
20	30 hp	Base load + hp Line to Line motor starts Four motor combination	Inductive & Resistive	10	200
21	100 kW	Base load	Resistive	10	210
22	50 hp	Base load + hp Soft Start motor start	Inductive & Resistive	15	220
23	100 kW	Base load	Resistive	10	230
24	50 hp	Base load + hp Line to Line motor start	Inductive & Resistive	15	240
25	100 kW	Base load	Resistive	10	250
End					

Table F8. BT005A test/table 4 as tested format.

Base Load – 150 kW					
Steps	Load Step	Comments	Load Type	Duration (seconds)	Total Test Time (seconds)
1	150 kW	Base load	Resistive	10	10
2	100 kW	Reduced load	Resistive	10	20
3	180 kW	180 kW total	Resistive	10	30
4	200 kW	200 kW total	Resistive	10	40
5	100 kW	Reduced load	Resistive	10	50
6	150 kW	Base load	Resistive	10	60
7	30 kW	180 kW total	Resistive	10	70
8	150 kW	Base load	Resistive	10	80
9	50 kW	200 kW total	Resistive	10	90
10	100 kW	Base Load	Resistive	10	100
11	150 kW	Base load	Resistive	10	110
12	30 kW	180 kW total	Resistive	10	120
13	150 kW	Base load	Resistive	10	130
14	50 kW	200 kW total	Resistive	10	140
15	150 kW	Base load	Resistive	10	150
16	5 hp	Base load + hp Line to Line motor start	Inductive & Resistive	10	160
17	150 kW	Base load	Resistive	10	170
18	10 hp	Base load + hp Line to Line motor starts Two motor combination	Inductive & Resistive	10	180
19	150 kW	Base load	Resistive	10	190
20	15 hp	Base load + hp Line to Line motor start	Inductive & Resistive	10	200
21	150 kW	Base load	Resistive	10	210
22	20 hp	Base load + hp Soft Start motor start	Inductive & Resistive	10	220
23	150 kW	Base load	Resistive	10	230
24	20 hp	Base load + hp Line to Line motor start Four motor combination	Inductive & Resistive	10	240
25	150 kW	Base load	Resistive	10	250
26	150 kW	Base load + hp Line to Line motor starts Three motor combination		10	260
27	150 kW	Base load	Resistive	10	270
28	25 hp	Base load + hp Line to Line motor starts Three motor combination	Inductive & Resistive	10	280

Base Load – 150 kW					
Steps	Load Step	Comments	Load Type	Duration (seconds)	Total Test Time (seconds)
29	150 kW	Base load	Resistive	10	290
30	30 hp	Base load + hp Line to Line motor starts Four motor combination	Inductive & Resistive	10	300
31	150 kW	Base load	Resistive	10	310

Table F9. BT005A test/table 5 as tested format.

Base Load – 170 kW					
Steps	Load Step	Comments	Load Type	Duration (seconds)	Total Test Time (seconds)
1	100	Base Load	Resistive	2	10
2	170 kW	Base load	Resistive	10	20
3	30 kW	200 kW total	Resistive	10	30
4	170 kW	Base load	Resistive	10	40
5	5 hp	Base load + hp Line to Line motor start	Inductive & Resistive	10	50
6	170 kW	Base load	Resistive	10	60
7	10 hp	Base load + hp Line to Line motor starts Two motor combination	Inductive & Resistive	10	70
8	170 kW	Base load	Resistive	10	80
9	15 hp	Base load + hp Line to Line motor start	Inductive & Resistive	10	90
10	20 hp	Base load + hp Soft Start motor start	Inductive & Resistive	10	100
11	170 kW	Base load	Resistive	10	110
12	20 hp	Base load + hp Line to Line motor start	Inductive & Resistive	10	120
13	170 kW	Base load	Resistive	10	130
14	25 hp	Base load + hp Line to Line motor starts Three motor combination	Inductive & Resistive	10	140
15	170 kW	Base load	Resistive	10	150
16	30 hp	Base load + hp Line to Line motor starts Four motor combination	Inductive & Resistive	10	160
17	170 kW	Base load	Resistive	10	170
End					

Appendix G: BT005B Test Plan

Outline

Two overload test formats will be performed on the fuel cell power plant (FCPP). The first test format will consist of applying a overload step for 1,2,3,and 4 second duration's to a base load of 200 kW. The cumulative resistive load steps will to be applied to the FCPP output until either an overload condition is reached (FCPP goes to idle or shutdown) or all steps are successfully applied. Data will be captured at high speed for each step load at selected test duration's. It is anticipated that the FCPP will either transfer to idle or shutdown when an overload condition is met. This test will end when either of the following event happenings: shutdown or idle condition or all steps are applied with no mishaps.

The second test format will consist of starting with the highest power level from the previous overload test that was able to operate for the maximum 4 second duration. This overload condition will be tested to see if a steady state continuous power condition is reached (10 second duration). The overload amount will be reduced at 5 kW steps if needed to obtain the overload steady state continuous operating condition of the FCPP.

Daily Start Up / Pre-Test Review (No Heat Recovery)

- Fuel Cell in Local Operation
- Manual Disconnect Switch (GI Load) Closed, MDS003
- Manual Disconnect Switch (GC Load) Closed, MDS001
- Grid Connected MCB Closed, MCB002
- Grid Independent MCB Closed, MCB001
- Cooling Module Operational
- Thermal Flow pump Off, PMP 410 & VFD 413
- Low Grade Heat valves Closed, TLB 412
- High Grade Heat valves Closed, TLB 422 & TLB 423
- Thermal Load Bank crossover valves Closed, TLB 420 & TLB 421
- Chilled Water Supply Valve Closed, TLB 425
- Verify Nitrogen Injection Valve Closed, FPB 758

- Verify Fuel Cell is operating on Natural Gas
- Verify Fuel Cell is at desired power level.

Test Procedure – Test Format 1

- 1.0 Verify Grid Independent loads off status.
- 2.0 Set up the desired Grid Independent test plan on CDAQ as outlined in test/table format 1 of this test plan.
- 3.0 Configure CDAQ data recording at $\frac{1}{2}$ second update rate for the miscellaneous & ELB data.
- 4.0 Set up portable high-speed data acquisition system to capture data at a sampling rate of **1000 samples/second** from the Resistive Load Bank (RLB) and Motor Load Bank (MLB).
- 5.0 Set up Dranetz 658 Disturbance Analyzer to record power quality data.
- 6.0 Connect PC to LDT port and select Grid Independent Load – disconnect.
- 7.0 Connect CTC's CDAQ (RADAR DAQ connection) cable to the LDT port.
- 8.0 **Initiate Test via CDAQ** – This sequence will begin the desired test as outlined in test/table format 1. The following data acquisition will also be initiated at the start of each test.
 - 8.1 UTC Fuel Cells RADAR data snapshot.
 - 8.2 Miscellaneous & ELB data acquisition (at $\frac{1}{2}$ second update)
 - 8.3 High-speed data acquisition (at 1000 samples/second)
 - 8.4 Dranetz 658 Disturbance Analyzer data recording
- 9.0 Perform desired test outlined in test/table format 1. This process will be automatically controlled via CDAQ. The following data acquisition shutdown will occur at the end of each test.
 - 9.1 UTC Fuel Cells RADAR data snapshot.
 - 9.2 Miscellaneous & ELB data acquisition
 - 9.3 High-speed data acquisition
 - 9.4 Dranetz 658 Disturbance Analyzer data recording
- 10.0 End BT005B test format 1 – reset power plant to the default operating condition.

Test Procedure – Test Format 2

- 1.0 Verify Grid Independent loads off status.
- 2.0 Configure CDAQ data recording at $\frac{1}{2}$ second update rate for the miscellaneous & ELB data.
- 3.0 Set up portable high-speed data acquisition system to capture data at a sampling rate of **1000 samples/second** from the Resistive Load Bank (RLB) and Motor Load Bank (MLB).
- 4.0 Set up Dranetz 658 Disturbance Analyzer to record power quality data.
- 5.0 Set up the desired step load outlined in test/table format 2 on CDAQ. Desired step load starting point determined from previous overload test. Test/table format 2 identifies all possible step loads from test format 1.
- 6.0 Connect PC to LDT port and select Grid Independent Load – disconnect.

- 7.0 Connect CTC's CDAQ (RADAR DAQ connection) cable to the LDT port.
- 8.0 **Initiate Test via CDAQ** – This sequence will apply the desired load to the FCPP for 10-second duration.
- 9.0 Go to step 5.0 and repeat with next lower step load if a ten second continuous operation was not met. Repeat steps 5.0 to 9.0 until a continuous operation condition was met for a applied load.
- 10.0 Set-up CDAQ with the load step that was able to operate continuously for ten-seconds.
- 11.0 **Initiate test via CDAQ** – The following data acquisition will parameters will be acquired during this test.
- 11.1 UTC Fuel Cells RADAR data snapshot.
- 11.2 Miscellaneous & ELB data acquisition (at ½ second update)
- 11.3 High-speed data acquisition (at 1000 samples/second)
- 11.4 Dranetz 658 Disturbance Analyzer data recording
- 12.0 Perform desired test. The following data acquisition shutdown will occur at the end of this test.
- 12.1 UTC Fuel Cells RADAR data snapshot.
- 12.2 Miscellaneous & ELB data acquisition
- 12.3 High-speed data acquisition
- 12.4 Dranetz 658 Disturbance Analyzer data recording
- 13.0 End BT005B test format 2 – reset power plant to the default operating condition.

Data Acquisition Parameters

Table G1. BT005B test, miscellaneous data acquisition parameters.

Fluid Flow Temperature In	Cross pressure	AP401
Fluid Flow Temperature Out	Inside Ambient Air Temperature	AP402
Outside Ambient Air Temperature	Discharge Air Temperature	AP403
		AP404
		AP405
		PT3000
		PT3001

Table G2. BT005B test, ELB data acquisition parameters status.

20 hp PWM Line Side	50 hp SS Line Side	50 kW Resistor – A	Fan 4 – 5 hp
20 hp PWM Load Side	50 hp SS Load Side	50 kW Resistor – B	Pump – 15 hp
20 hp SS Line Side	50 hp SS Enabler	50 kW Resistor – C	
20 hp SS Load Side	5 kW Resistor	50 kW Resistor – D	
20 hp SS Enabler	10 kW Resistor	Fan 1 – 5 hp	
20 hp SS Starter	20 kW Resistor – A	Fan 2 – 5 hp	
50 hp SS Starter	20 kW Resistor – B	Fan 3 – 5 hp	

Table G3. BT005B test, ELB data acquisition parameters values

L1-N Voltage	L2-N Voltage	L3-N Voltage
RLB L1 Current	RLB L2 Current	RLB L3 Current
MLB KWattmeter		

Table G4. BT005B test, high speed data acquisition parameters.

MLB Phase 1 – Instant. Amps	RLB Phase 1 – RMS Amps	Phase 3 – L/N Instant. Volts
MLB Phase 2 – Instant. Amps	RLB Phase 2 – RMS Amps	Phase 1 – L/N RMS Volts
MLB Phase 3 – Instant. Amps	RLB Phase 3 – RMS Amps	Phase 2 – L/N RMS Volts
MLB kW	Phase 1 – L/N Instant. Volts	Phase 3 – L/N RMS Volts
Stack – DC Instant. Volts	Phase 2 – L/N Instant. Volts	

Table G5. BT005B test table format 1.

Base Load – 200 kW					
Steps	Load Step	Comments	Load Type	Duration (seconds)	Total Test Time (seconds)
1	200 kW	Base load	Resistive	5	5
2	10 kW	210 kW total	Resistive	1	6
3	200 kW	Base load	Resistive	5	11
4	10 kW	210 kW total	Resistive	2	13
5	200 kW	Base load	Resistive	5	18
6	10 kW	210 kW total	Resistive	3	21
7	200 kW	Base load	Resistive	5	26
8	10 kW	210 kW total	Resistive	4	30
9	200 kW	Base load	Resistive	5	35
10	20 kW	220 kW total	Resistive	1	36
11	200 kW	Base load	Resistive	5	41
12	20 kW	220 kW total	Resistive	2	43
13	200 kW	Base load	Resistive	5	48
14	20 kW	220 kW total	Resistive	3	51
15	200 kW	Base load	Resistive	5	56
16	20 kW	220 kW total	Resistive	4	60
17	200 kW	Base load	Resistive	5	65
18	30 kW	230 kW total	Resistive	1	66

Base Load – 200 kW					
Steps	Load Step	Comments	Load Type	Duration (seconds)	Total Test Time (seconds)
19	200 kW	Base load	Resistive	5	71
20	30 kW	230 kW total	Resistive	2	73
21	200 kW	Base load	Resistive	5	78
22	30 kW	230 kW total	Resistive	3	81
23	200 kW	Base load	Resistive	5	86
24	30 kW	230 kW total	Resistive	4	90
25	200 kW	Base load	Resistive	5	95
26	35 kW	235 kW total	Resistive	1	96
27	200 kW	Base load	Resistive	5	101
28	35 kW	235 kW total	Resistive	2	103
29	200 kW	Base load	Resistive	5	108
30	35 kW	235 kW total	Resistive	3	111
31	200 kW	Base load	Resistive	5	116
32	35 kW	235 kW total	Resistive	4	120
33	200 kW	Base load	Resistive	5	125
Base Load – 200 kW					
Steps	Load Step	Comments	Load Type	Duration (seconds)	Total Test Time (seconds)
34	40 kW	240 kW total	Resistive	1	126
35	200 kW	Base load	Resistive	5	131
36	40 kW	240 kW total	Resistive	2	133
37	200 kW	Base load	Resistive	5	138
38	40 kW	240 kW total	Resistive	3	141
39	200 kW	Base load	Resistive	5	146
40	40 kW	240 kW total	Resistive	4	150
41	200 kW	Base load	Resistive	5	155
42	45 kW	245 kW total	Resistive	1	156
43	200 kW	Base load	Resistive	5	161
44	45 kW	245 kW total	Resistive	2	163
45	200 kW	Base load	Resistive	5	168
46	45 kW	245 kW total	Resistive	3	171
47	200 kW	Base load	Resistive	5	176
48	45 kW	245 kW total	Resistive	4	180
49	200 kW	Base load	Resistive	5	185
50	50 kW	250 kW total	Resistive	1	186
51	200 kW	Base load	Resistive	5	191
52	50 kW	250 kW total	Resistive	2	193
53	200 kW	Base load	Resistive	5	198
54	50 kW	250 kW total	Resistive	3	201

Base Load – 200 kW					
Steps	Load Step	Comments	Load Type	Duration (seconds)	Total Test Time (seconds)
55	200 kW	Base load	Resistive	5	206
56	50 kW	250 kW total	Resistive	4	210
57	200 kW	Base load	Resistive	5	215
End					

Table G6. BT005B test, table format 2A.

Steps	Load Step	Continuous Operation (>10 second duration)	Load Type	Duration (seconds)
1	250 kW	Yes – test done No – procedure to next step	Resistive	10
2	245 kW	Yes – test done No – procedure to next step	Resistive	10
3	240 kW	Yes – test done No – procedure to next step	Resistive	10
4	235 kW	Yes – test done No – procedure to next step	Resistive	10
5	230 kW	Yes – test done No – procedure to next step	Resistive	10
6	225 kW	Yes – test done No – procedure to next step	Resistive	10
7	220 kW	Yes – test done No – procedure to next step	Resistive	10
8	215 kW	Yes – test done No – procedure to next step	Resistive	10
9	210 kW	Yes – test done No – procedure to next step	Resistive	10
End				

Table G7. BT005B test, table format 2B.

Steps	Load Step	Comments	Load Type	Duration (seconds)	Total Test Time (seconds)
1	100 kW	Increase load	Resistive	2	2
2	150 kW	Increase load	Resistive	5	7
3	200 kW	Increase load	Resistive	5	12
4	220 kW	Base load	Resistive	10	22
5	200 kW	Reduced load	Resistive	10	32
6	220 kW	Base load	Resistive	10	42
7	200 kW	Reduced load	Resistive	5	47
8	0	Removed load		2	49

Appendix H: BT005D Test Plan

Outline

The Power Quality Test will be performed on the fuel cell power plant (FCPP) to indicate the relative quantity of supplied power from the fuel cell while serving non-linear loads. The FCPP will be configured for grid independent mode. An applied resistive or resistive & inductive load will be connected to the FCPP electrical output. Data will be captured for each test at high speed. Each test will end when either of the following event happenings: shutdown or idle condition or test completed with no mishaps. A total of nine (9) tests are anticipated to be completed. Three (3) main tests each with three (3) sub tests.

Daily Start Up / Pre-Test Review (No Heat Recovery)

- Fuel Cell in Local Operation
- Manual Disconnect Switch (GI Load) Closed, MDS003
- Manual Disconnect Switch (GC Load) Closed, MDS001
- Grid Connected MCB Closed MCB002
- Grid Independent MCB Closed, MCB001
- Cooling Module Operational
- Thermal Flow pump Off, PMP 410 & VFD 413
- Low Grade Heat valves Closed, TLB 412
- High Grade Heat valves Closed, TLB 422 & TLB 423
- Thermal Load Bank crossover valves Closed, TLB 420 & TLB 421
- Chilled Water Supply Valve Closed, TLB 425
- Verify Nitrogen Injection Valve Closed, FPB 758
- Verify Fuel Cell is operating on Natural Gas
- Verify Fuel Cell is at desired power level.

Test Procedure

- 1.0 Verify Grid Independent loads off status.

- 2.0 With the LDT computer installed switch the power plant over to grid independent mode.
- 3.0 Replace the LDT cable with the DAQ cable for sampling.
- 4.0 Set up the test plan on CDAQ in accordance with the applied loads identified in the tables.
- 5.0 Set up portable high-speed data acquisition system to capture data at a sampling rate of **1000 samples/second** from the Resistive Load Bank (RLB) & motor load bank (MLB).
- 6.0 Set up Dranetz 658 Disturbance Analyzer to record power quality data.
- 7.0 Capture a RADAR snapshot of all steady-state values and set points.
- 8.0 Start high-speed data acquisition.
- 9.0 Start Dranetz 658 Disturbance Analyzer data recording.
- 10.0 **Initiate Test via CDAQ** – This sequence will begin the desired test line number as outlined in the Test Tables. The following data acquisition parameters will be acquired during this test.
 - 10.0 UTC Fuel Cells RADAR data snapshot.
 - 10.1 Miscellaneous & ELB data acquisition (at ½ second update)
 - 10.2 High-speed data acquisition (at 1000 samples/second)
 - 10.3 Dranetz 658 Disturbance Analyzer data recording
- 11.0 Perform the following data acquisition shutdown
 - 11.0 UTC Fuel Cells RADAR data snapshot.
 - 11.1 Miscellaneous & ELB data acquisition
 - 11.2 High-speed data acquisition
 - 11.3 Dranetz 658 Disturbance Analyzer data recording
- 12.0 Repeat for each table sequence.
- 13.0 End BT005D test – reset power plant to the default operating condition.

Data Acquisition Parameters

Table H1. BT005D test, miscellaneous data acquisition parameters.

Cooling Module Information From CTC Sensors	Thermal Management System Parameters	Cell Stack Assembly (CSA) cross pressure from sensors.
Fluid Flow Temperature In	AP401	PT3000
Fluid Flow Temperature Out	AP402	PT3001
Outside Ambient Air Temperature	AP403	
Inside Ambient Air Temperature	AP404	
Discharge Air Temperature	AP405	

Table H2. BT005D test, high speed data acquisition parameters.

MLB Phase 1 – Instant. Amps	RLB Phase 1 – RMS Amps	Phase 3 – L/N Instant. Volts
MLB Phase 2 – Instant. Amps	RLB Phase 2 – RMS Amps	Phase 1 – L/N RMS Volts
MLB Phase 3 – Instant. Amps	RLB Phase 3 – RMS Amps	Phase 2 – L/N RMS Volts
MLB kW	Phase 1 – L/N Instant. Volts	Phase 3 – L/N RMS Volts
Stack – DC Instant. Volts	Phase 2 – L/N Instant. Volts	

Table H3. BT005D test, ELB data acquisition parameters status.

20 hp PWM Line Side	50 hp SS Line Side	50 kW Resistor – A	Fan 4 – 5 hp	
20 hp PWM Load Side	50 hp SS Load Side	50 kW Resistor – B	Pump – 15 hp	
20 hp SS Line Side	50 hp SS Enabler	50 kW Resistor – C		
20 hp SS Load Side	5 kW Resistor	50 kW Resistor – D		
20 hp SS Enabler	10 kW Resistor	Fan 1 – 5 hp		
20 hp SS Starter	20 kW Resistor – A	Fan 2 – 5 hp		
50 hp SS Starter	20 kW Resistor – B	Fan 3 – 5 hp		

Table H4. BT005D test, ELB data acquisition parameters values.

L1-N Voltage	L2-N Voltage	L3-N Voltage
RLB L1 Current	RLB L2 Current	RLB L3 Current
MLB KWattmeter		

Test 1 Full Load Resistive

Table H5. BT005D test 1, full load resistive, 100% Speed.

	Resistive Load kW	Nonlinear Load hp	Description	Duration	Total Test Time
0	0	0	Start	0	0
1	50	0		5	5
2	100	0		5	10
3	100	20	100 % speed	10	20
4	120	20	100 % speed	5	25
5	140	20	100 % speed	5	30
6	160	20	100 % speed	5	35
7	180	20	100 % speed	5	40
8	160	20	100 % speed	5	45
9	140	20	100 % speed	5	50
10	120	20	100 % speed	5	55
11	100	20	100 % speed	5	60
12	100	0		5	65
13	50	0		5	70

Table H6. BT005D test 1, full load resistive, 50% speed.

	Resistive Load kW	Nonlinear Load hp	Description	Duration	Total Test Time
0	0	0	Start	0	0
1	50	0		5	5
2	100	0		5	10
3	100	20	50 % speed	10	20
4	120	20	50 % speed	5	25
5	140	20	50 % speed	5	30
6	160	20	50 % speed	5	35
7	180	20	50 % speed	5	40
8	160	20	50 % speed	5	45
9	140	20	50 % speed	5	50
10	120	20	50 % speed	5	55
11	100	20	50 % speed	5	60
12	100	0		5	65

Table H7. BT005D test 1, full load resistive, 25% speed.

	Resistive Load kW	Nonlinear Load hp	Description	Duration	Total Test Time
0	0	0	Start	0	0
1	50	0		5	5
2	100	0		5	10
3	100	20	25 % speed	10	20
4	120	20	25 % speed	5	25
5	140	20	25 % speed	5	30
6	160	20	25 % speed	5	35
7	180	20	25 % speed	5	40
8	160	20	25 % speed	5	45
9	140	20	25 % speed	5	50
10	120	20	25 % speed	5	55
11	100	20	25 % speed	5	60
12	100	0		5	65
13	50	0		5	70

Test 2 Light Load Resistive

Table H8. BT005D test 2, light load resistive, 100% speed.

	Resistive Load kW	Nonlinear Load hp	Description	Duration	Total Test Time
0	0	0	Start	0	0
1	50	0		5	5
2	50	20	100 % speed	10	15
3	25	20	100 % speed	5	20
4	10	20	100 % speed	5	25
5	0	20	100 % speed	5	30
6	0	0		5	35

Table H9. BT005D test 2, light load resistive, 50% speed.

	Resistive Load kW	Nonlinear Load hp	Description	Duration	Total Test Time
0	0	0	Start	0	0
1	50	0		5	5
2	50	200	50 % speed	10	15
3	25	20	50 % speed	5	20
4	10	20	50 % speed	5	25
5	0	20	50 % speed	5	30
6	0	0		5	35

Table H10. BT005D test 2, light load resistive, 25% speed.

	Resistive Load kW	Nonlinear Load hp	Description	Duration	Total Test Time
0	0	0	Start	0	0
1	50	0		5	5
2	50	20	25 % speed	10	15
3	25	20	25 % speed	5	20
4	10	20	25 % speed	5	25
5	0	20	25 % speed	5	30
6	0	0		5	35

Test 3 Motor and Resistive Loads

Table H11. BT005D test 3, motor and resistive loads, 100% speed.

	Resistive Load kW	Motor Load hp	Nonlinear Load hp	Description	Duration	Total Test Time
1	0	10	20	100 % speed	5	5
2	0	20	20	100 % speed	5	10
3	0	35	20	100 % speed	5	15
4	50	35	20	100 % speed	5	20
5	100	35	20	100 % speed	5	25
6	145	35	20	100 % speed	5	30
7	100	35	20	100 % speed	5	35
8	50	35	20	100 % speed	5	40
9	0	35	20	100 % speed	5	45
10	0	20	20	100 % speed	5	50
11	0	10	20	100 % speed	5	55
12	0	0	0		5	60

Table H12. BT005D test 3, motor and resistive loads, 50% speed.

	Resistive Load kW	Motor Load hp	Nonlinear Load hp	Description	Duration	Total Test Time
1	0	10	20	50 % speed	5	5
2	0	20	20	50 % speed	5	10
3	0	35	20	50 % speed	5	15
4	50	35	20	50 % speed	5	20
5	100	35	20	50 % speed	5	25
6	145	35	20	50 % speed	5	30
7	100	35	20	50 % speed	5	35
8	50	35	20	50 % speed	5	40
9	0	35	20	50 % speed	5	45
10	0	20	20	50 % speed	5	50
11	0	10	20	50 % speed	5	55
12	0	0	0		5	60

Table H13. BT005D test 3, motor and resistive loads, 25% speed.

	Resistive Load kW	Motor Load hp	Nonlinear Load hp	Description	Duration	Total Test Time
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1	0	10	20	25 % speed	5	5
2	0	20	20	25 % speed	5	10
3	0	35	20	25 % speed	5	15
4	50	35	20	25 % speed	5	20
5	100	35	20	25 % speed	5	25
6	145	35	20	25 % speed	5	30
7	100	35	20	25 % speed	5	35
8	50	35	20	25 % speed	5	40
9	0	35	20	25 % speed	5	45
10	0	20	20	25 % speed	5	50
11	0	10	20	25 % speed	5	55
12	0	0	0		5	60

Transient Test, Motor Startup

Table H14. BT005D transient test, motor startup, 50 hp motor across the line start.

	Resistive Load kW	Motor Load hp	Nonlinear Load hp	Description	Duration	Total Test Time
1	0	0	0		3	3
2	50	0	0		5	
3	100	0	0		5	
4	100	50	0	Across Line	10	
5	100	0	0		2	
6	50	0	0		2	
7	0	0	0		2	
8	OFF					

Table H15. BT005D transient test, motor startup, 20 hp motor ASD operation.

	Resistive Load kW	Motor Load hp	Nonlinear Load hp	Description	Duration	Total Test Time
1	0	0	0		3	3
2	50	0	0		5	
3	100	0	0		5	
4	100	0	20	25% Speed	10	
5	100	0	0		2	
6	50	0	0		2	
7	0	0	0		2	
8	OFF					

Appendix I: BT008 Test Plan

Title: Test Plan FCTP BT008A
Water Quality for SN9194
Test BT008A

REV. LTR.	AUTHOR	RELEASE NO.	DATE
—	LeAnne Debias		06 Nov 2001

PRODUCT FILE ADDRESS: Test Plan BT008A.DOC			
POWER PLANT/PROGRAM	SYSTEM & TAG NO.	PART NO.	DOCUMENT NO.
PC25C			FCTP BT008A PAGE 117 OF 5

REVISION RECORD				
DASH NO. LTR	REL NO.	LTR	DESCRIPTION	DATE
		—	ORIGINAL ISSUE	06 Nov 01

Objective

Assess the water quality within the power plant cooling and water treatment system.

Length Of Test

Collect samples for field analytical methods at a minimum interval of once each week and samples for laboratory analytical methods at a minimum interval of 4 weeks.

Materials Required

Water sample containers.

Ports Location for the Samples

- CTC Deionized make-up water
- (HV453)
- TMS Loop (HV431)
- Degasifier Column from the 4-in. PVC water return on the top of the water storage tank.

Test Setup

No special test set-up is required.

Test Program

- 1.0 Document the following information:
 - 1.1 Date and time for each sample taken.
 - 1.2 Determine whether a test is being performed and DAQ is running.
 - 1.3 If DAQ is running, record the Test Name and capture a RADAR snapshot of all steady-state values and set points.
 - 1.4 If DAQ is not running begin recording Fuel Cell RADAR Data using a sampling rate of 5 minutes and begin recording MISC Data at a sampling rate of 60 seconds, input a Test Name, and begin DAQ.
 - 1.5 Record the hours of operation on the fuel cell, then determine the hours of operation since the last resin change-out, and record on LAB188 or LAB189.
- 2.0 Perform sampling at each of the following locations as required:
 - CTC Deionized make-up water
 - on board water storage tank from the hand valve located on the hose line feeding the charcoal bed
 - Feed Water at the final mixed-bed deionizing tank (HV453)
 - TMS Loop (HV431)

- Degasifier Column from the 4-in. PVC water return on the top of the water storage tank (NOTE: perform this test only if results for previous locations indicate problems and UTC Fuel Cells request this location to be sampled).
- 3.0 Log information required on Lab Form LAB188, and analyze:
- 3.1 Collect a sample and analyze immediately for Dissolved Oxygen using Chem-et kits.
 - 3.2 Collect an additional sample and analyze immediately for Conductivity.
 - 3.3 Collect an additional sample and analyze immediately for pH.
 - 3.4 Collect 1 liter of sample in a plastic bottle and analyze for turbidity using Millipore filters and compare with Babcock and Wilcox Turbidity Charts.
 - 3.5 If performing sampling for analysis using laboratory methods, log information on Lab Form LAB189, and analyze:
 - 3.5.1 Collect a sample and analyze immediately for Dissolved Oxygen using the Yellow Springs Dissolved Oxygen Meter.
 - 3.5.2 Collect an additional sample and analyze immediately for Conductivity.
 - 3.5.3 Collect an additional sample and analyze immediately for pH.
 - 3.5.4 Collect a sample in a sterile sample bag and analyze for bacteria.
 - 3.5.5 Collect 1 liter of sample in a plastic bottle and analyze for silica, Total Dissolved Solids, Total Suspended Solids, Total Organic Carbon, and turbidity (using the Nephelometer).
 - 3.5.6 Analyze for ions (nitrate, nitrite, chloride, sulfate, and phosphate) using the Waters hpLC.
 - 3.5.7 Analyze for metals (iron, copper, calcium, magnesium, and sodium) using the Varian Liberty 110 Inductively Coupled Plasma Optical Emission Spectrophotometer.
- 4.0 If a previous test was running, capture a RADAR snapshot of all steady-state values and set points, record Test Name, date and time. If DAQ was started for water sampling, collect a RADAR Snapshot and exit DAQ.

Appendix J: Peak Load Shutdown Test

Test Plan For Residential Scale Fuel Cell Power Plants



Title: Peak Load Shutdown Test

Revision Letter	Author	Release No.	Date
P. 1	Jeffrey D. Stangl	Preliminary	January 31, 2003

Product File Address: TBD			
Power Plant Manufacturer	System Tag No.	Technology of the Fuel Cell Power Plant	Document No.
TBD	TBD	TBD	TBD

Objective

The purpose of the Peak Load Shutdown Test is to determine the peak load supply power of the fuel cell being evaluated for both constant and changing electrical loads. The individual outputs of each fuel cell power plant to be evaluated may vary, and must be documented in the test notes. Primary evaluation shall concentrate on the fuel cell's ability to supply power without the complicating factors of large inductive transients and large impulse current. Initial testing shall consist of various levels of resistive loading.

The peak load shutdown test shall determine the average peak load for three test operations. This value will be reduced by 5 percent to determine a starting load for the Sustained Load Test.

Length of Test

The length of the test is dependent on the peak load capabilities of the fuel cell power plant being evaluated. Example: Approximately 17 minutes will be required to test for a peak load of 5 kW (cf. Table J1).

Material Required

Propane, Hydrogen, or Natural Gas fuel.

Test Setup

- Follow the start up procedure in the operating instructions of the fuel cell power plant being evaluated
- Testing shall begin with the fuel cell in the off-line mode
- Prepare all data acquisition equipment for testing.

Test Procedure

1. Monitor the input of the fuel required by the fuel cell being tested. (Hydrogen, Natural Gas, etc.) Fuel cell output current (DC or AC), fuel cell output voltage (DC or AC), output load profile, air exhaust discharge rate, air exhaust discharge temperature, fuel cell stack temperature, and the ambient air temperature at the sampling rate as indicated in the data acquisition parameter table.
2. Start recording.
3. Turn on the fuel cell to be evaluated according to the manufacturer instructions.
4. Add resistive load segments in 50 watt sequences, remaining at each step for 10 seconds.
5. Continue increasing the load until the fuel cell system shuts down from overload.
6. Document the final load step.
7. Stop Recording
8. Restart the Fuel Cell being evaluated in the on – line mode according to the manufacturer instructions.

9. Repeat the test three times.
10. Average the three (3) documented load values that the fuel cell shut down at to obtain the peak load.
11. End test.

Data Acquisition Parameters

Table J1. Peak load shutdown test, data acquisition parameters.

Electrical Information from CTC Sensors.	Fuel Supply Rate from CTC Sensor	Environmental Information from CTC Sensors
Sampling Rate 10 per second	Sampling Rate 10 per second	Sampling Rate 10 per second
Gross Output, Stack Current	Inlet Fuel Mass Flow	Air Discharge Rate
Net Output Current (AC or DC)		Air Discharge Temperature
Output Voltage (AC or DC)		Ambient Air Temperature
Output Load Profile		Fuel Cell Stack Temperature

Table J2. Peak load shutdown test.

Test #	Resistive Loads Watts	Duration Seconds	Total Test Time Minutes/seconds	Comments
1	0	10	0:10	
2	50	10	0:20	
3	100	10	0:30	
4	150	10	0:40	
5	200	10	0:50	
6	250	10	0:60	
7	300	10	1:10	
8	350	10	1:20	
9	400	10	1:30	
10	450	10	1:40	
11	500	10	1:50	
12	550	10	2:00	
13	600	10	2:10	
14	650	10	2:20	
15	700	10	2:30	
16	750	10	2:40	
17	800	10	2:50	
18	850	10	3:00	
19	900	10	3:10	
20	950	10	3:20	
21	1000	10	3:30	
22	1050	10	3:40	
23	1100	10	3:50	
24	1150	10	4:00	

Test #	Resistive Loads Watts	Duration Seconds	Total Test Time Minutes/seconds	Comments
25	1200	10	4:10	
26	1250	10	4:20	
27	1300	10	4:30	
28	1350	10	4:40	
29	1400	10	4:50	
30	1450	10	5:00	
31	1500	10	5:10	
32	1550	10	5:20	
33	1600	10	5:30	
34	1650	10	5:40	
35	1700	10	5:50	
36	1750	10	6:00	
37	1800	10	6:10	
38	1850	10	6:20	
39	1900	10	6:30	
40	1950	10	6:40	
41	2000	10	6:50	
42	2050	10	7:00	
43	2100	10	7:10	
44	2150	10	7:20	
45	2200	10	7:30	
46	2250	10	7:40	
47	2300	10	7:50	
48	2350	10	8:00	
49	2400	10	8:10	
50	2450	10	8:20	
51	2500	10	8:30	
52	2550	10	8:40	
53	2600	10	8:50	
54	2650	10	9:00	
55	2700	10	9:10	
56	2750	10	9:20	
57	2800	10	9:30	
58	2850	10	9:40	
59	2900	10	9:50	
60	2950	10	10:00	
61	3000	10	10:10	
62	3050	10	10:20	
63	3100	10	10:30	
64	3150	10	10:40	
65	3200	10	10:50	
66	3250	10	11:00	

Test #	Resistive Loads Watts	Duration Seconds	Total Test Time Minutes/seconds	Comments
67	3300	10	11:10	
68	3350	10	11:20	
69	3400	10	11:30	
70	3450	10	11:40	
71	3500	10	11:50	
72	3550	10	12:00	
73	3600	10	12:10	
74	3650	10	12:20	
75	3700	10	12:30	
76	3750	10	12:40	
77	3800	10	12:50	
78	3850	10	13:00	
79	3900	10	13:10	
80	3950	10	13:20	
81	4000	10	13:30	
82	4050	10	13:40	
83	4100	10	13:50	
84	4150	10	14:00	
85	4200	10	14:10	
86	4250	10	14:20	
87	4300	10	14:30	
88	4350	10	14:40	
89	4400	10	14:50	
90	4450	10	15:00	
91	4500	10	15:10	
92	4550	10	15:20	
93	4600	10	15:30	
94	4650	10	15:40	
95	4700	10	15:50	
96	4750	10	16:00	
97	4800	10	16:10	
98	4850	10	16:20	
99	4900	10	16:30	
100	4950	10	16:40	
101	5000	10	16:50	
102	5050	10	17:00	
103	5100	10	17:10	
104	5150	10	17:20	
105	5200	10	17:30	
106	5250	10	17:40	
107	5300	10	17:50	
108	5350	10	18:00	

Test #	Resistive Loads Watts	Duration Seconds	Total Test Time Minutes/seconds	Comments
109	5400	10	18:10	
110	5450	10	18:20	
111	5500	10	18:30	
112	5550	10	18:40	
113	5600	10	18:50	
114	5650	10	19:00	
115	5700	10	19:10	
116	5750	10	19:20	
117	5800	10	19:30	
118	5850	10	19:40	
119	5900	10	19:50	
120	5950	10	20:00	
121	6000	10	20:10	
122	6050	10	20:20	
123	6100	10	20:30	
124	6150	10	20:40	
125	6200	10	20:50	
126	6250	10	21:00	
127	6300	10	21:10	
128	6350	10	21:20	
129	6400	10	21:30	
130	6450	10	21:40	
131	6500	10	21:50	
132	6550	10	22:00	
133	6600	10	22:10	
134	6650	10	22:20	
135	6700	10	22:30	
136	6750	10	22:40	
137	6800	10	22:50	
138	6850	10	23:00	
139	6900	10	23:10	
140	6950	10	23:20	
141	7000	10	23:30	

Appendix K: Sustained Load Test



Test Plan For Residential Scale Fuel Cell Power Plants

Title: Sustained Load Test

Revision Letter	Author	Release No.	Date
P. 1	Jeffrey D. Stangl	Preliminary	January 31, 2003

Product File Address: TBD			
Power Plant Manufacturer	System Tag No.	Technology of the Fuel Cell Power Plant	Document No.
TBD	TBD	TBD	TBD

Objective

The purpose of the Sustained Load Test is to determine the maximum sustained load capable of the fuel cell being evaluated for both constant and changing electrical loads. The individual outputs of each fuel cell power plant to be evaluated may vary, and must be documented in the test notes. Primary evaluation shall concentrate on the fuel cell's ability to supply power without the complicating factors of large inductive transients and large impulse current. Initial testing shall consist of various levels of resistive loading.

Length of Test

The length of this test for a given fuel cell power plant will be determined by the peak load shutdown value determined during the peak load shutdown test. Five (5) second load intervals will be used to reach the calculated sustained load. A 60 minute test will be completed at the calculated sustained load.

Note: If the fuel cell power plant fails at any time during the sustained load, the load will have to be reduced as is indicated in the test procedure, and the test will be restarted.

Material Required

Propane, Hydrogen, or Natural Gas fuel.

Test Setup

- Follow the start up operating instructions for the fuel cell power plant being evaluated.
- Testing shall begin with the fuel cell power plant in the off – line mode.
- Prepare all data acquisition equipment for testing.
- Calculate the maximum sustained load, for the fuel cell power plant being evaluated, by decreasing the average of the Peak Load Test by 5%.
- Round down the 95% calculated figure to the next value divisible by 50 watts.
- This calculated value will be the initial sustained load for this testing.

Test Procedure

1. Monitor the input of the fuel required by the fuel cell being tested. (Hydrogen, Natural Gas, etc.) Fuel cell output current (DC or AC), fuel cell output voltage (DC or AC), output load profile, air exhaust discharge rate, air exhaust discharge temperature, fuel cell stack temperature, and the ambient air temperature at the sampling rate as indicated in the data acquisition parameter table.
2. Turn on the fuel cell power plant being evaluated, according to the manufacturers operating instructions.
3. Add resistive load segments in 50 watt increments, remaining at each step for five (5) seconds.

4. Continue increasing the load until the calculated maximum sustained peak load is reached.
5. Start recording.
6. Maintain the maximum sustained load for 60 minutes.
 - a. If a shutdown is experienced prior to the completion of the test, document the power level, time, and date.
 - b. If the fuel cell power plant being evaluated has shut down during the test, reduce the power level by 5%, and round down to the next value divisible by 50 watts.
 - c. If the fuel cell power plant being evaluated operates continuously for 1 hr, increase the power requirement by 2.5%, and begin the test procedure again.
7. Stop recording.
8. Restart the fuel cell power plant being evaluated to the on – line mode according to the manufacturers operating instructions.
9. Repeat steps 1 through 7, to achieve three (3) complete hour-long test runs.
10. Test data shall be maintained for only completed tests. Results will include both the sustained load level and the efficiency of the fuel cell in HHV and LHV units.
11. End test.

Data Acquisition Parameters

Table K1. Sustained load test, data acquisition parameters.

Electrical Information from CTC Sensors.	Fuel Supply Rate from CTC Sensor	Environmental Information from CTC Sensors
Sampling Rate 10 per second	Sampling Rate 10 per second	Sampling Rate 10 per second
Gross Output, Stack Current	Inlet Fuel Mass Flow	Air Discharge Rate
Net Output Current (AC or DC)		Air Discharge Temperature
Output Voltage (AC or DC)		Ambient Air Temperature
Output Load Profile		Fuel Cell Stack Temperature

Appendix L: Sustained Load Step Test



Test Plan For Residential Scale Fuel Cell Power Plants

Title: Sustained Load Step Test

Revision Letter	Author	Release No.	Date
P. 1	Jeffrey D. Stangl	Preliminary	January 31, 2003

Product File Address: TBD			
Power Plant Manufacturer	System Tag No.	Technology of the Fuel Cell Power Plant	Document No.
TBD	TBD	TBD	TBD

Objective

The purpose of the Sustained Load Step Test is to determine the fuel cell power plant capabilities of operating with impulse transitions, up to and including 100 percent of the sustained load that was determined during the sustained load test. Primary evaluation shall concentrate on the fuel cell's ability to supply power without the complicating factors of large inductive transients and large impulse current. Initial testing shall consist of various levels of resistive loading.

Length of Test

The length of the test is dependent on where the fuel cell power plant fails while under test. (cf. Test Procedure and Table L1.)

Material Required

Propane, Hydrogen, or Natural Gas fuel.

Daily Start Up / Pre – Test Review

- Follow the start up operating instructions for the fuel cell power plant being evaluated.
- Testing shall begin with the fuel cell power plant in the off – line mode.
- Prepare all data acquisition equipment for testing.
- Determine the average sustained load, for the fuel cell power plant under evaluation, from the three completed Steady State, Sustained Load Tests.
- This value will be the 100% sustainable load for this testing.
- Divide this value by 20 to obtain a value that is 5% of the total. This value will be used as the incrementing value in the test.

Test Procedure

1. Monitor the input of the fuel required by the fuel cell being tested. (Hydrogen, Natural Gas, etc.) Fuel cell output current (DC or AC), fuel cell output voltage (DC or AC), output load profile, air exhaust discharge rate, air exhaust discharge temperature, fuel cell stack temperature, and the ambient air temperature at the sampling rate as indicated in the data acquisition parameter table.
2. Turn on the fuel cell power plant being evaluated, according to the manufacturers operating instructions.
3. Start recording.
4. Add resistive load segments in 50 watt sequences, remaining at each step for five (5) seconds.
5. Continue increasing the load until reaching the starting load point of the Sustained Load Test as indicated in Table 1.
6. Add a resistive load segment as indicated in Table 1.
7. Cycle this segment on and off, in increments of 1 second on, and 1 second off, for 60 seconds.

- a. If a shutdown is experienced any time during the execution of the test, stop recording, document the power level, time, and date.
 - b. If the fuel cell under evaluation has shut down during the test, decrease the additive load by 2.5% of the sustainable load, document the revision, and restart the test procedure.
 - c. If the fuel cell being evaluated operates continuously throughout each test, continue on with step nine of this test procedure.
8. Restart the fuel cell power plant being evaluated to the off – line mode according to the manufacturers operating instructions.
 9. Repeat the entire test procedure until it has been completed three times successfully, to assure repeatability.
 10. End test.

Data Acquisition Parameters

Table L1. Sustained load step test, data acquisition parameters.

Electrical Information from CTC Sensors.	Fuel Supply Rate from CTC Sensor	Environmental Information from CTC Sensors
Sampling Rate 10 per second	Sampling Rate 10 per second	Sampling Rate 10 per second
Gross Output, Stack Current	Inlet Fuel Mass Flow	Air Discharge Rate
Net Output Current (AC or DC)		Air Discharge Temperature
Output Voltage (AC or DC)		Ambient Air Temperature
Output Load Profile		Fuel Cell Stack Temperature

Table L2. Sustained load step test, 100% sustained load capacity test.

Test #	Starting Load	Additive Load	Duration Seconds	Total Minutes	Comments
1	95% Peak Load	5%	60	1	
2	90% Peak Load	10%	60	2	
3	85% Peak Load	15%	60	3	
4	80% Peak Load	20%	60	4	
5	75% Peak Load	25%	60	5	
6	70% Peak Load	30%	60	6	
7	65% Peak Load	35%	60	7	
8	60% Peak Load	40%	60	8	
9	55% Peak Load	45%	60	9	
10	50% Peak Load	50%	60	10	
11	45% Peak Load	55%	60	11	
12	40% Peak Load	60%	60	12	
13	35% Peak Load	65%	60	13	

Test #	Starting Load	Additive Load	Duration Seconds	Total Minutes	Comments
14	30% Peak Load	70%	60	14	
15	25% Peak Load	75%	60	15	
16	20% Peak Load	80%	60	16	
17	15% Peak Load	85%	60	17	
18	10% Peak Load	90%	60	18	
19	5% Peak Load	95%	60	19	
20	0% Peak Load	100%	60	20	

Appendix M: Overload Test



Test Plan For Residential Scale Fuel Cell Power Plants

Title: Overload Test

Revision Letter	Author	Release No.	Date
P. 1	Jeffrey D. Stangl	Preliminary	January 31, 2003

Product File Address: TBD			
Power Plant Manufacturer	System Tag No.	Technology of the Fuel Cell Power Plant	Document No.
TBD	TBD	TBD	TBD

Objective

The purpose of the Overload Test is to determine the fuel cell power plant's capability of operating with impulse transients up to 200 percent of the sustained load capacity. Primary evaluation shall concentrate on the fuel cell's ability to supply power without the complicating factors of large inductive transients and large impulse current. Initial testing shall consist of various levels of resistive loading.

Test Length

The duration of the test is dependent on how many of the test tables are completed. Each of the six (6) test tables will require approximately 60 minutes to complete. Maximum test time assuming the power plant completes all six (6) tests is approximately 360 minutes.

Material Required

Propane, Hydrogen, or Natural Gas fuel.

Test Setup

- Follow the start up operating instructions for the fuel cell power plant being evaluated.
- Testing shall begin with the fuel cell power plant in the off – line mode.
- Prepare all data acquisition equipment for testing.
- Determine the average sustained load, for the fuel cell power plant under evaluation, from the three completed Steady State, Sustained Load Tests.
- Values of 10%, 20%, 30%, 40%, 50%, and 100% shall be applied for this test.

Test Procedure

1. Monitor the input of the fuel required by the fuel cell being tested. (Hydrogen, Natural Gas, etc.) Fuel cell output current (DC or AC), fuel cell output voltage (DC or AC), output load profile, air exhaust discharge rate, air exhaust discharge temperature, fuel cell stack temperature, and the ambient air temperature at the sampling rate as indicated in the data acquisition parameter table.
2. Turn on the fuel cell power plant being evaluated, according to the manufacturers operating instructions.
3. Add resistive load in 50-watt increments, remaining at each step for five (5) seconds.
4. Continue increasing the load until reaching the starting load point of the Transient Test as indicated in Tables M1 through M6. The starting load point for this test shall be a percentage of the Sustained Load Test, which is indicated in the Starting Load column of Tables M1 through M6.
5. Start recording.
6. Add a resistive load segment as indicated in Tables M1 through M6.

- a. Remain at the designated percentage of load until the fuel cell power plant fails, or until 10 minutes have passed. Then stop recording.
 - b. If the fuel cell power plant fails, document the power level, duration of test until the failure occurred, time, and date. Then reduce the overload percentage by 5%, and restart the test.
7. Restart the fuel cell power plant being evaluated to the off – line mode according to the manufacturers operating instructions.
8. Repeat the entire test procedure until all tests in Tables M1 through M6, have been completed three (3) times.
9. End test.

Data Acquisition Parameters

Table M1. Overload test, data acquisition parameters.

Electrical Information from CTC Sensors.	Fuel supply rate From CTC sensor	Environmental Information From CTC sensors
Sampling Rate 10 per second	Sampling Rate 10 per second	Sampling Rate 10 per second
Gross Output, Stack Current	Inlet Fuel Mass Flow	Air Discharge Rate
Net Output Current (AC or DC)		Air Discharge Temperature
Output Voltage (AC or DC)		Ambient Air Temperature
Output Load Profile		Fuel Cell Stack Temperature

Overload Test Tables

Table M2. Overload test, 10% overload.

Test #	Starting Load	Additive Load	Duration Seconds	Comments
1	80% of Peak Load	30% of Peak Load		
2	60% of Peak Load	50% of Peak Load		
3	40% of Peak Load	70% of Peak Load		
4	20% of Peak Load	90% of Peak Load		
5	0% of Peak Load	110% of peak Load		

Table M3. Overload test, 20% overload.

Test #	Starting Load	Additive Load	Duration Seconds	Comments
1	80% of Peak Load	40% of Peak Load		
2	60% of Peak Load	60% of Peak Load		
3	40% of Peak Load	80% of Peak Load		
4	20% of Peak Load	100% of Peak Load		
5	0% of Peak Load	120% of peak Load		

Table M4. Overload test, 30% overload.

Test #	Starting Load	Additive Load	Duration Seconds	Comments
1	80% of Peak Load	50% of Peak Load		
2	60% of Peak Load	70% of Peak Load		
3	40% of Peak Load	90% of Peak Load		
4	20% of Peak Load	110% of Peak Load		
5	0% of Peak Load	130% of peak Load		

Table M5. Overload test, 40% overload.

Test #	Starting Load	Additive Load	Duration Seconds	Comments
1	80% of Peak Load	60% of Peak Load		
2	60% of Peak Load	80% of Peak Load		
3	40% of Peak Load	100% of Peak Load		
4	20% of Peak Load	120% of Peak Load		
5	0% of Peak Load	140% of peak Load		

Table M6. Overload test, 50% overload.

Test #	Starting Load	Additive Load	Duration Seconds	Comments
1	80% of Peak Load	70% of Peak Load		
2	60% of Peak Load	90% of Peak Load		
3	40% of Peak Load	110% of Peak Load		
4	20% of Peak Load	130% of Peak Load		
5	0% of Peak Load	150% of peak Load		

Table M7. Overload test, 100% overload

Test #	Starting Load	Additive Load	Duration Seconds	Comments
1	80% of Peak Load	120% of Peak Load		
2	60% of Peak Load	140% of Peak Load		
3	40% of Peak Load	160% of Peak Load		
4	20% of Peak Load	180% of Peak Load		
5	0% of Peak Load	200% of peak Load		

Appendix N: Residential Profile Test



Test Plan For Residential Scale Fuel Cell Power Plants

Title: Residential Profile Test

Revision Letter	Author	Release No.	Date
P. 1	Jeffrey D. Stangl	Preliminary	January 31, 2003

Product File Address: TBD			
Power Plant Manufacturer	System Tag No.	Technology of the Fuel Cell Power Plant	Document No.
TBD	TBD	TBD	TBD

Objective

The purpose of the Residential Profile Test is to verify the fuel cell power plant's capability of operating in a residential setting, over a 5-day period. In this test, a profile will be established, and residential electrical appliances will be used to serve as the load. Loads and load changes shall be automated so that each fuel cell power plant being tested is subjected to the same load pattern.

Test Length

The Residential Profile is anticipated to take 120 hrs to complete. The test is planned to have a total of 480 steps at 15 minute intervals. (Reference Table N1 for an example of a 24 hr test.)

Material Required

Propane, Hydrogen, or Natural Gas fuel.

Test Setup

- Follow the start up operating instructions for the fuel cell power plant being evaluated.
- Testing shall begin with the fuel cell power plant in the off – line mode.
- Prepare all data acquisition equipment for testing.
- The test shall run automated for five (5) days, to simulate power requirements for a typical one family residence, for a working family.

Test Procedure

1. Monitor the input of the fuel required by the fuel cell being tested. (Hydrogen, Natural Gas, etc.) Fuel cell output current (DC or AC), fuel cell output voltage (DC or AC), output load profile, air exhaust discharge rate, air exhaust discharge temperature, fuel cell stack temperature, and the ambient air temperature at the sampling rate as indicated in the data acquisition parameter table.
2. Turn on the fuel cell power plant being evaluated, according to the manufacturers operating instructions.
3. Begin recording.
4. Start the automated Residential Profile Test that will control the on/off switching of the load devices.
5. If the fuel cell power plant fails at any time during the test, document the power level, duration of the test, time and date. Then restart the test from the point of failure.
6. The test shall be complete at the end of the 5th day.
7. End test.

Data Acquisition Parameters

Table N1. Residential profile test. data acquisition parameters.

Electrical Information from <i>CTC</i> Sensors.	Fuel Supply Rate from <i>CTC</i> Sensor	Environmental Information from <i>CTC</i> Sensors
Sampling Rate 10 per second	Sampling Rate 10 per second	Sampling Rate 10 per second
Gross Output, Stack Current	Inlet Fuel Mass Flow	Air Discharge Rate
Net Output Current (AC or DC)		Air Discharge Temperature
Output Voltage (AC or DC)		Ambient Air Temperature
Output Load Profile		Fuel Cell Stack Temperature

Table N2. Residential profile test, 24-hr example (page 1).

[illegible]

Table N3. Residential profile test, 24-hr example (page 2).

Step #	Test Day	Time	Bedroom #1 Light 60w	Bedroom #1 Clock Radio 9w	Bedroom #1 T.V 220w	Bedroom #2 Light 60w	Bedroom #2 Clock Radio 9w	Bedroom #3 Light 60w	Bedroom #3 Clock Radio 9w	Living Room Light #1 60w	Living Room Light #2 60w	Vacuum Sweeper	Living Room Television 220w	Living Room Stereo 150w	Dining Room Light #1 60w	Dining Room light #2 60w	Kitchen Electric Range	Kitchen Refrigerator 840w	Kitchen Light #1 100w	Kitchen Couter Top Lights 200w	Kitchen Coffee Pot 950w	Kitchen Crock Pot 340w	Kitchen Microwave 950w	Kitchen Exhaust Fan 50w	Bathroom Light 100w	Bathroom Exhaust Fan 13w	Curling Iron 38w	Blow Drier 1875w	Dish Washer 1300w	Hot water Heat -Pump 165w	Basement Lights 240w	Well Pump	Central Air Conditioning	Dehumidifier	Computer and Monitor	Laser Printer	Clothes Drier 720w	Clothes Washer 720w	Total Watts			
25	1	6:00		9			9		9								840																								867	
26	1	6:15		9			9		9																																27	
27	1	6:30		9			9		9																						165										192	
28	1	6:45		9			9		9																																27	
29	1	7:00		9			9		9								840																								867	
30	1	7:15		9			9		9																						165										192	
31	1	7:30		9			9		9																																27	
32	1	7:45		9			9		9																																27	
33	1	8:00	60	9		60	9	60	9					5			840	100	200	950					100	13					165											2580
34	1	8:15	60	9	220	60	9	60	9	60			220	5					100	200	950				100	13	38	1875														3988
35	1	8:30	60	9	220	60	9	60	9	60			220	5			840	100	200	950		950			100	13		1875		165												5905
36	1	8:45		9		60	9	60	9	60			220	5					100	200	950				100	13																1795
37	1	9:00		9			9	60	9	60	60		220	5	60		840	100	200	950					100					1300	165											4147
38	1	9:15		9			9	60	9	60	60		220	5	60				100		950									1300												2842
39	1	9:30		9			9		9	60	60	360	220	5																1300												2032
40	1	9:45	60	9			9		9	60	60		220	5																1300	165											1897
41	1	10:00	60	9			9		9	60	60	360	220	5			840								100					1300		240								720	3992	
42	1	10:15		9		60	9		9	60	60		220	5																1300										720	2452	
43	1	10:30		9		60	9		9	60	60	360	220	5					100											1300										720	2912	
44	1	10:45		9			9	60	9	60	60		220	5																1300	165									720	2617	
45	1	11:00		9			9	60	9	60	60	360	220	5			840								100							240							720	2692		
46	1	11:15		9			9		9				220	5	60	60																240							720	720	2052	
47	1	11:30		9			9		9				220	5	60	60																							720	720	1812	
48	1	11:45		9			9		9				220	5								950								165									720	720	2807	

Table N4. Residential profile test, 24-hr example (page 3).

Step #	Test Day	Time	Bedroom #1 Light 60w	Bedroom #1 Clock Radio 9w	Bedroom #1 T.V. 220w	Bedroom #2 Light 60w	Bedroom #2 Clock Radio 9w	Bedroom #3 Light 60w	Bedroom #3 Clock Radio 9w	Living Room Light #1 60w	Living Room Light #2 60w	Vacuum Sweeper	Living Room Television 220w	Living Room Stereo 150w	Dining Room Light #1 60w	Dining Room light #2 60w	Kitchen Electric Range	Kitchen Refrigerator 840w	Kitchen Light #1 100w	Kitchen Counter Top Lights 200w	Kitchen Coffee Pot 950w	Kitchen Crock Pot 340w	Kitchen Microwave 950w	Kitchen Exhaust Fan 50w	Bathroom Light 100w	Bathroom Exhaust Fan 13w	Curling Iron 38w	Blow Drier 1875w	Dish Washer 1300w	Hot water Heat -Pump 165w	Basement Lights 240w	Well Pump	Central Air Conditioning	Dehumidifier	Computer and Monitor	Laser Printer	Clothes Drier 720w	Clothes Washer 720w	Total Watts			
49	1	12:00		9			9		9				220	5				840	100						100	13													720	720	2745	
50	1	12:15		9			9		9				220	5					100																				720		1072	
51	1	12:30		9			9		9				220	5																		240							720		1212	
52	1	12:45		9			9		9				220	5																	165								720		1137	
53	1	13:00		9			9		9				220	5				840							100															720		1912
54	1	13:15		9			9		9				220	5					100																					720		1072
55	1	13:30		9			9		9				220	5																										720		972
56	1	13:45		9			9		9				220	5																	165									720		1137
57	1	14:00		9			9		9		60			150				840														165									1242	
58	1	14:15		9			9		9		60			150											100																337	
59	1	14:30		9			9		9	60	60			150																											297	
60	1	14:45	60	9		60	9		9	60	60			150											100						165										682	
61	1	15:00	60	9		60	9	60	9	60	60		220					840																							1387	
62	1	15:15	60	9		60	9	60	9	60	60		220					840																							1387	
63	1	15:30	60	9		60	9	60	9	60			220												100						165										752	
64	1	15:45	60	9		60	9	60	9	60			220																		165									652		
65	1	16:00		9		60	9	60	9	60			220				840							50	100																1417	
66	1	16:15		9		60	9	60	9	60			220		60	60			100	200				50																	1787	
67	1	16:30		9		60	9		9	60			220		60	60			100	200			950	50																	1787	
68	1	16:45		9			9		9	60			220		60	60		840	100	200	950			50	100	13				165											2845	
69	1	17:00		9			9		9	60			220		60	60			100	200	950																				1677	
70	1	17:15	60	9	220				9	60			220		60	60			100	200	950																				1948	
71	1	17:30	60	9	220		9		9	60			220		60	60		840	100	200	950				100	13				1300											4210	
72	1	17:45	60	9	220		9		9	60			220		60	60			100	200	950										1300	165										3422

Table N5. Residential profile test, 24-hr example (page 4).

Step #	Test Day	Time	Bedroom #1 Light 60w	Bedroom #1 Clock Radio 9w	Bedroom #1 T.V. 220w	Bedroom #2 Light 60w	Bedroom #2 Clock Radio 9w	Bedroom #3 Light 60w	Bedroom #3 Clock Radio 9w	Living Room Light #1 60w	Living Room Light #2 60w	Vacuum Sweeper	Living Room Television 220w	Living Room Stereo 150w	Dining Room Light #1 60w	Dining Room light #2 60w	Kitchen Electric Range	Kitchen Refrigerator 840w	Kitchen Light #1 100w	Kitchen Couter Top Lights 200w	Kitchen Coffee Pot 950w	Kitchen Crock Pot 340w	Kitchen Microwave 950w	Kitchen Exhaust Fan 50w	Bathroom Light 100w	Bathroom Exhaust Fan 13w	Curling Iron 38w	Blow Drier 1875w	Dish Washer 1300w	Hot water Heat -Pump 165w	Basement Lights 240w	Well Pump	Central Air Conditioning	Dehumidifier	Computer and Monitor	Laser Printer	Clothes Drier 720w	Clothes Washer 720w	Total Watts		
73	1	18:00	60	9	220		9		9	60			220						100	200	950				100				1300												3237
74	1	18:15	60	9	220		9		9	60			220					840	100	200	950								1300												3977
75	1	18:30	60	9	220		9		9	60			220												100				1300												1987
76	1	18:45		9		60	9		9	60			220															1300	165											1832	
77	1	19:00		9		60	9		9	60			220												100				1300												1767
78	1	19:15		9		60	9		9	60			220					840										1300												2507	
79	1	19:30		9		60	9		9	60			220												100	13														480	
80	1	19:45		9			9		9	60			220																165											472	
81	1	20:00		9			9		9	60			220					840							100	13			165												1425
82	1	20:15	60	9	220		9		9	60			220												100	13														700	
83	1	20:30	60	9	220		9	60	9	60			220												100	13	1875													2635	
84	1	20:45	60	9	220		9	60	9	60			220						100										165											912	
85	1	21:00	60	9	220	60	9	60	9	60			220					840	100																					1647	
86	1	21:15	60	9	220	60	9	60	9	60			220					840					950		100															2597	
87	1	21:30	60	9	220	60	9	60	9	60			220																											707	
88	1	21:45		9			9		9	60			220																165											472	
89	1	22:00		9			9		9	60			220						100										165											572	
90	1	22:15		9	220		9		9	60			220					840							100															1467	
91	1	22:30		9	220		9		9	60			220																											347	
92	1	22:45		9	220		9		9										100																					347	
93	1	23:00		9	220		9		9									840											165											1252	
94	1	23:15		9			9		9																100															127	
95	1	23:30		9			9		9																															27	
96	1	23:45		9			9		9																				165											192	
97	1	0:00		9			9		9									840																						867	

Appendix O: Residential Profile Test with Respect to Temperature and Humidity



Test Plan For Residential Scale Fuel Cell Power Plants

Title: Residential Profile Test with respect to Temperature and Humidity

Revision Letter	Author	Release No.	Date
P. 1	Jeffrey D. Stangl	Preliminary	January 31, 2003

Product File Address: TBD			
Power Plant Manufacturer	System Tag No.	Technology of the Fuel Cell Power Plant	Document No.
TBD	TBD	TBD	TBD

Objective

The purpose of the Residential Profile with respect to Temperature and Humidity Test is to verify the fuel cell power plant's capability of operating in a residential setting, under conditions of high/low humidity, and high/low temperature over a 24-hr period. The fuel cell power plant being evaluated shall be placed in the temperature and humidity chamber for testing. Table O1 lists the temperature and humidity settings for each test. The automated test (Steps 1 through

96) of the Residential Profile Test shall be used for each of the Temperature and Humidity test periods. The timing for each load step during this segment will be reduced from 15 minutes to 5 minutes.

Test Length

The test article shall be operated over the residential load profile, reducing the time duration between load steps to 5 minutes. Each residential sequence shall operate at a minimum of 11 temperature steps distributed over the manufacturer's specified temperature range. Each temperature range shall be duplicated at the three levels of humidity as specified within the test table. Humidity capability will be bound by a 4° C dew point requirement on the environmental chamber, thus not allowing some humidity set points to be achieved. The load sequencing of the Residential Profile test shall be held at a steady state level during the transitioning of temperature and humidity set points.

Material Required

Propane, Hydrogen, or Natural Gas fuel.

Test Setup

- Follow the start up operating instructions for the fuel cell power plant being evaluated.
- Testing shall begin with the fuel cell power plant in the off – line mode.
- Prepare all data acquisition equipment for testing.
- The test shall run automated for 45 days, to simulate power requirements for a typical one family residence, for a working family.

Test Procedure

1. Monitor the input of the fuel required by the fuel cell being tested. (Hydrogen, Natural Gas, etc.) Fuel cell output current (DC or AC), fuel cell output voltage (DC or AC), output load profile, air exhaust discharge rate, air exhaust discharge temperature, fuel cell stack temperature, and the ambient air temperature at the sampling rate as indicated in the data acquisition parameter table.
2. Turn on the fuel cell power plant being evaluated, according to the manufacturers operating instructions.
3. Begin recording.

4. Start the automated Residential Profile Test that will control the on/off switching of the load devices.
5. Control the environmental chamber to the specified temperature and humidity as required. Temperatures shall be determined by using a minimum of 11 steps distributed over the manufacturer's suggested temperature operating range.
6. If the fuel cell power plant fails at any time during the test, document the power level, duration of the test, time and date. Then restart the test from the point of failure.
7. Repeat steps 1 through 5 for each test. Efficiency will be reported as LHV and HHV for each hour of the test and, to the extent possible, curves will be developed as a function of ambient temperature and load.
8. End test after complete.

Data Acquisition Parameters

Table O1. Residential profile test, data acquisition parameters

Electrical Information from CTC Sensors.	Fuel Supply Rate from CTC Sensor	Environmental Information from CTC Sensors
Sampling Rate 10 per second	Sampling Rate 10 per second	Sampling Rate 10 per second
Gross Output, Stack Current	Inlet Fuel Mass Flow	Air Discharge Rate
Net Output Current (AC or DC)		Air Discharge Temperature
Output Voltage (AC or DC)		Ambient Air Temperature
Output Load Profile		Fuel Cell Stack Temperature

Table O2. Residential profile test, temperature and humidity test table

Test #	Temperature °F	Humidity %
1	50% of operating range	20
2	50% of operating range	50
3	50% of operating range	95
4	60% of operating range	20
5	60% of operating range	50
6	60% of operating range	95
7	70% of operating range	20
8	70% of operating range	50
9	70% of operating range	95
10	80% of operating range	20
11	80% of operating range	50
12	80% of operating range	95
13	90% of operating range	20
14	90% of operating range	50
15	90% of operating range	95
16	100% of operating range	20
17	100% of operating range	50

Test #	Temperature °F	Humidity %
18	100% of operating range	95
19	40% of operating range	20
20	40% of operating range	50
21	40% of operating range	95
22	30% of operating range	20
23	30% of operating range	50
24	30% of operating range	95
25	20% of operating range	20
26	20% of operating range	50
27	20% of operating range	95
28	10% of operating range	20
29	10% of operating range	50
30	10% of operating range	95
31	Lowest operating point	20
32	Lowest operating point	50
33	Lowest operating point	95
Freeze durability with test article shutdown and prepared as manufacturers requirements	Lowest operating point	No requirements

Appendix P: Combined Heat and Power Test



Test Plan For Residential Scale Fuel Cell Power Plants

Title: Combined Heat and Power Test

Revision Letter	Author	Release No.	Date
P. 1	Jeffrey D. Stangl	Preliminary	January 31, 2003
Product File Address: TBD			
Power Plant Manufacturer	System Tag No.	Technology of the Fuel Cell Power Plant	Document No.
TBD	TBD	TBD	TBD

Objective

The purpose of the Combined Heat and Power Test is to measure and map the thermal output of a given Fuel Cell Power Plant under various load conditions. A Thermal Load Bank with all of the appropriate measurement and control devices will be used as the testing device.

Length of Test

The length of this test will be approximately 25 testing hours plus the initial start up time of the fuel cell.

Material Required

Propane, Hydrogen, or Natural Gas fuel.

Test Setup

- Follow the start up procedure in the operating instructions of the fuel cell power plant being evaluated.
- Set the output power of the FCPP to the first step output power shown in the Combined Heat and Power test table.
- Prepare all data acquisition equipment for testing and begin recording.

Test Procedure

1. Monitor the data collected by the measurement devices in Data Acquisition Parameters table.
2. Capture data that the FCPP computer system and sensors collect.
3. Start recording.
4. Turn the fuel cell to be evaluated on according to the manufacturer instructions.
5. Follow the Combined Heat and Power test table.
6. Stop recording.
7. A map will be developed showing thermal recovery in Btu/Hr on the vertical axis and return temperature from the load to the fuel cell in degrees Fahrenheit (°F) on the horizontal axis with curves for various constant supply temperatures from the fuel cell to the load in increments of 10 °F for data developed during the test variable parameters.
8. Tests will be conducted while maintaining a 60 °F, an 80 °F, and a 100 °F return temperature to the fuel cell.

Data Acquisition Parameters

Table P1. Combined heat and power test, data acquisition parameters.

Electrical Information from CTC or Manufactures Sensors.	Fuel Supply Rate From CTC Sensor	Environmental Information from CTC or Manufacturers Sensors
Sampling Rate 10 per second	Sampling Rate 10 per second	Sampling Rate 10 per second
Gross Output, Stack Current	Inlet Fuel Mass Flow	Air Discharge Rate
Net Output Current (AC or DC)		Air Discharge Temperature
Output Voltage (AC or DC)		Ambient Air Temperature
Output Load Profile		Fuel Cell Stack Temperature
Process Flow Rate		

Electrical Information from CTC or Manufactures Sensors.	Fuel Supply Rate From CTC Sensor	Environmental Information from CTC or Manufacturers Sensors
Chilled water Flow rate		
Hot side system inlet temperature		
Hot side system outlet temperature		
Cold side system inlet temperature		
Cold side system outlet temperature		

Table P2. Combined heat and power test.

Step #	F CPP Power Output	Time at step	Process Water Flow Rate
1	20% of Max output	1 Hour	5% of max Flow Rate
2	20% of Max output	1 Hour	10% of max Flow Rate
3	20% of Max output	1 Hour	20% of max Flow Rate
4	20% of Max output	1 Hour	40% of max Flow Rate
5	20% of Max output	1 Hour	60% of max Flow Rate
6	20% of Max output	1 Hour	80% of max Flow Rate
7	20% of Max output	1 Hour	100% of max Flow Rate
8	40% of Max output	1 Hour	5% of max Flow Rate
9	40% of Max output	1 Hour	10% of max Flow Rate
10	40% of Max output	1 Hour	20% of max Flow Rate
11	40% of Max output	1 Hour	40% of max Flow Rate
12	40% of Max output	1 Hour	60% of max Flow Rate
13	40% of Max output	1 Hour	80% of max Flow Rate
14	40% of Max output	1 Hour	100% of max Flow Rate
15	60% of Max output	1 Hour	5% of max Flow Rate
16	60% of Max output	1 Hour	10% of max Flow Rate
17	60% of Max output	1 Hour	20% of max Flow Rate
18	60% of Max output	1 Hour	40% of max Flow Rate
19	60% of Max output	1 Hour	60% of max Flow Rate
20	60% of Max output	1 Hour	80% of max Flow Rate
21	60% of Max output	1 Hour	100% of max Flow Rate
22	80% of Max output	1 Hour	5% of max Flow Rate
23	80% of Max output	1 Hour	10% of max Flow Rate
24	80% of Max output	1 Hour	20% of max Flow Rate
25	80% of Max output	1 Hour	40% of max Flow Rate
26	80% of Max output	1 Hour	60% of max Flow Rate
27	80% of Max output	1 Hour	80% of max Flow Rate
28	80% of Max output	1 Hour	100% of max Flow Rate
29	100% of Max output	1 Hour	5% of max Flow Rate
30	100% of Max output	1 Hour	10% of max Flow Rate
31	100% of Max output	1 Hour	20% of max Flow Rate
32	100% of Max output	1 Hour	40% of max Flow Rate
33	100% of Max output	1 Hour	60% of max Flow Rate
34	100% of Max output	1 Hour	80% of max Flow Rate
35	100% of Max output	1 Hour	100% of max Flow Rate

NOTE: The maximum flow rate of the process water shall be the lower of: the maximum process flow rate of the fuel cell being evaluated, or the flow rate giving a 100 °F outlet at a 60 °F inlet, or the maximum flow rate of the thermal load bank which is 15gpm.

Appendix Q: 15 Amp Circuit Breaker Overload Test



Test Plan For Residential Scale Fuel Cell Power Plants

Title: 15 Amp Circuit Breaker Overload Test

Revision Letter	Author	Release No.	Date
P. 1	Jeffrey D. Stangl	Preliminary	January 31, 2003
Product File Address: TBD			
Power Plant Manufacturer	System Tag No.	Technology of the Fuel Cell Power Plant	Document No.
TBD	TBD	TBD	TBD

Objective

The objective of the 15 Amp Breaker Overload Test is to determine the fuel cell power plants capability to successfully open a 15-amp breaker under an overload condition, while maintaining power to circuits that are not overloaded.

Test Length

The length of the test will depend on the ability of the fuel cell power plant to trip

15-amp breaker without the complicating factor of an inverter, or power plant shutdown.

Maximum test time is anticipated to be 15.5 minutes. (Reference Table Q1.)

Material Required

Propane, Hydrogen, or Natural Gas fuel.

Test Setup

- Follow the start up operating instructions for the fuel cell power plant being evaluated.
- Testing shall begin with the fuel cell power plant in the off – line mode.
- Prepare all data acquisition equipment for testing.
- Prepare two electronic load banks for test procedure in accordance with manufacturer instructions.

Test Procedure

1. Monitor the input of the fuel required by the fuel cell being tested. (Hydrogen, Natural Gas, etc.) Fuel cell output current (DC or AC), fuel cell output voltage (DC or AC), electronic load bank # 1 current, electronic load bank # 2 current, air exhaust discharge rate, air exhaust discharge temperature, fuel cell stack temperature, and the ambient air temperature at the sampling rate as indicated in the data acquisition parameter table.
2. Turn on the fuel cell power plant being evaluated, according to the manufacturers operating instructions.
3. Start recording.
4. Set number one electronic load bank to a constant current of 25 amps.
5. Set number two electronic load bank to constant current, and increase the current in.
5 amp increments every 30 seconds until the circuit breaker trips, or until the fuel cell power plant fails.
6. Repeat test three times to obtain a pattern of repeatability.
7. Testing report shall include voltage to load curves.

Data Acquisition Parameters

Table Q1. Fifteen (15) amp circuit breaker overload test, data acquisition parameters.

Electrical Information from CTC Sensors.	Fuel Supply Rate from CTC Sensor	Environmental Information from CTC Sensors
Sampling Rate 10 per second	Sampling Rate 10 per second	Sampling Rate 10 per second
Gross Output, Stack Current	Inlet Fuel Mass Flow	Air Discharge Rate
Net Output Current (AC or DC)		Air Discharge Temperature
Output Voltage (AC or DC)		Ambient Air Temperature
Electronic Load Bank # 1 Current		Fuel Cell Stack Temperature
Electronic Load Bank # 2 Current		

Table Q2. Fifteen (15) amp circuit breaker overload test.

Test #	Test Time Minute/Seconds	Load Bank # 1 30 amp Breaker	Load Bank # 2 15 amp Breaker	15 amp Breaker Failure (Yes/No)
1	0:30	25 amps	0.5 amp	
2	1:30	25 amps	1.0 amp	
3	2:00	25 amps	1.5 amps	
4	2:30	25 amps	2.0 amps	
5	3:00	25 amps	2.5 amps	
6	3:30	25 amps	3.0 amps	
7	4:00	25 amps	3.5 amps	
8	4:30	25 amps	4.0 amps	
9	5:00	25 amps	4.5 amps	
10	5:30	25 amps	5.0 amps	
11	6:00	25 amps	5.5 amps	
12	6:30	25 amps	6.0 amps	
13	7:00	25 amps	6.5 amps	
14	7:30	25 amps	7.0 amps	
15	8:00	25 amps	7.5 amps	
16	8:30	25 amps	8.0 amps	
17	9:00	25 amps	8.5 amps	
18	9:30	25 amps	9.0 amps	
19	10:00	25 amps	9.5 amps	
20	10:30	25 amps	10.0 amps	
21	11:00	25 amps	10.5 amps	
22	11:30	25 amps	11.0 amps	
23	12:00	25 amps	11.5 amps	
24	12:30	25 amps	12.0 amps	
25	13:00	25 amps	12.5 amps	
26	13:30	25 amps	13.0 amps	
27	14:00	25 amps	13.5 amps	
28	14:30	25 amps	14.0 amps	
29	15:00	25 amps	14.5 amps	
30	15:30	25 amps	15.0 amps	

Test #	Test Time Minute/Seconds	Load Bank # 1 30 amp Breaker	Load Bank # 2 15 amp Breaker	15 amp Breaker Failure (Yes/No)
31	16:00	25 amps	15.5 amps	
32	16:30	25 amps	16.0 amps	
33	17:00	25 amps	16.5 amps	
34	17:30	25 amps	17.0 amps	
35	18:00	25 amps	17.5 amps	
36	18:30	25 amps	18.0 amps	
37	19:00	25 amps	18.5 amps	
38	19:30	25 amps	19.0 amps	
39	20:00	25 amps	19.5 amps	
40	21:30	25 amps	20 amps	

Appendix R: 15 Amp Breaker Short Circuit Test



Test Plan For Residential Scale Fuel Cell Power Plants

Title: 15 Amp Breaker Short Circuit Test

Revision Letter	Author	Release No.	Date
P. 1	Jeffrey D. Stangl	Preliminary	January 31, 2003
Product File Address: TBD			
Power Plant Manufacturer	System Tag No.	Technology of the Fuel Cell Power Plant	Document No.
TBD	TBD	TBD	TBD

Objective

The objective of the 15 Amp Breaker-Short Circuit Test is to determine the fuel cell power plants capability to successfully open a 15-amp breaker when subjected to a short circuit, while maintaining power to other circuits.

Test Length

The length of the test will depend on the ability of the fuel cell power plant to trip a 15-amp breaker without the complicating factor of an inverter, or power plant shutdown.

Material Required

Propane Hydrogen, or Natural Gas fuel.

Test Setup

- Follow the start up operating instructions for the fuel cell power plant being evaluated.
- Testing shall begin with the fuel cell power plant in the off – line mode.
- Prepare all data acquisition equipment for testing.
- Prepare the electronic load bank to operate with a load of 25 amps for test procedure in accordance with manufacturers instructions.
- Prepare a resistive load bank of paralleled 100-watt light bulbs and switches, with a paralleled shorting switch for the test.

Test Procedure

1. Monitor the input of the fuel required by the fuel cell being tested. (Hydrogen, Natural Gas, etc.) Fuel cell output current (DC or AC), fuel cell output voltage (DC or AC), electronic load bank current, resistive load bank current, air exhaust discharge rate, air exhaust discharge temperature, fuel cell stack temperature, and the ambient air temperature at the sampling rate as indicated in the data acquisition parameter table.
2. Turn on the fuel cell power plant being evaluated, according to the manufacturers operating instructions.
3. Start recording.
4. Set static load on electronic load bank to a constant current of 25 amps.
5. Record the output voltage of the 15-amp breaker to be subjected to the short circuit.
6. Short the 15-amp breaker.
7. Record the status of the breaker after it was subjected to the short.
8. Record the status of the fuel cell and inverter including the voltage over time curve.
9. Repeat test three times to obtain a pattern of repeatability.
10. Repeat the test procedure using a setting of the electronic load bank to the load determined by the result of the Sustained Load Test.

Data Acquisition Parameters

Table R1. Fifteen (15) amp breaker short circuit test, data acquisition parameters.

Electrical Information from CTC Sensors.	Fuel Supply Rate from CTC Sensor	Environmental Information from CTC Sensors
Sampling Rate 10 per second	Sampling Rate 10 per second	Sampling Rate 10 per second
Gross Output, Stack Current	Inlet Fuel Mass Flow	Air Discharge Rate
Net Output Current (AC or DC)		Air Discharge Temperature
Output Voltage (AC or DC)		Ambient Air Temperature
Electronic Load Bank Current		Fuel Cell Stack Temperature
Short Circuit Current		
Short Circuit – Breaker Output Voltage		

Table R2. Fifteen (15) amp breaker short circuit test, short circuit test table.

Test #	Electronic Load Bank Current	Shorting Circuit Status	Shorting Circuit Breaker Output Voltage
1	25 amps	Open	
2	25 amps	Closed	

Appendix S: Power Grid Simulation Test



Test Plan For Residential Scale Fuel Cell Power Plants

Title: Power Grid Simulation Test

Revision Letter	Author	Release No.	Date
P. 1	Jeffrey D. Stangl	Preliminary	January 31, 2003

Product File Address: TBD			
Power Plant Manufacturer	System Tag No.	Technology of the Fuel Cell Power Plant	Document No.
TBD	TBD	TBD	TBD

Objective

The objective of Grid Simulation is to develop a characteristic profile for a given residential scale fuel cell power plant, specifically how it operates with respect to grid variations. Variations, such as simultaneous or independent transients, voltage surges/sags, frequency deviation, voltage phase differentiation, and waveform distortion.

Test Length

A total of five (5) tests are planned; each will vary in duration. (Reference Test Procedures and Tables S1, S2, and S3 for duration of each test.)

Material Required

Propane Hydrogen or Natural Gas fuel.

Test Setup

- Follow the start up operating instructions for the fuel cell power plant being evaluated.
- Testing shall begin with the fuel cell power plant in the off – line mode.
- Prepare all data acquisition equipment for testing.
- Prepare the Grid Simulator for testing according to the manufacturer instructions.

Test Procedure

1. Monitor the input of the fuel required by the fuel cell being tested. (Hydrogen, Natural Gas, etc.) Fuel cell output current (DC or AC), fuel cell output voltage (DC or AC), electronic load bank current, resistive load bank current, air exhaust discharge rate, air exhaust discharge temperature, fuel cell stack temperature, and the ambient air temperature at the sampling rate as indicated in the data acquisition parameter table.
2. Turn on the fuel cell power plant being evaluated, according to the manufacturers operating instructions.
3. Turn on resistive load bank and set the related circuit parameters so that the fuel cell sees a Q of 2.5 at 60 Hz.
4. Start Recording.
5. For each test a graph will be prepared showing the test parameter and the fuel cell voltage output and timing during shutdown or disconnect.
6. Perform the following grid simulation tests according to the respective procedure and Test Tables.

Test 1-Frequency Deviation Test

1. The grid simulator shall be initially set to operate to the fuel cell power plant grid independent output frequency.
2. Equally distribute a total load of 50% of capacity across both legs of the fuel cell power plant output if applicable.
3. The time spent at each step shall be one minute.
4. Increase the Grid Simulator Frequency by .01 Hz increments a minute above an initial setting of 60 Hz.
5. Increase the frequency until the fuel cell power plant shuts down, or the fuel cell power plant goes into grid independent mode.
6. Reset the Grid Simulator to the Fuel Cell Power Plant frequency and if necessary restart the fuel cell power plant.
7. Decrease the Grid Simulator frequency by .01 HZ, and remain at each new frequency value for one minute.
8. Decrease the frequency until the total decreased value is 1 Hz, the fuel cell power plant shuts down, or the fuel cell power plant goes into grid independent mode.
9. Reset the Grid Simulator to the starting frequency and, if necessary, restart the fuel cell power plant.
10. Repeat Frequency Deviation Test three times to obtain a pattern of repeatability.

Test 2-Voltage Sag/Surge Test

1. Equally distribute a total load of 50% of capacity, across both legs of the fuel cell power plant output, if applicable.
2. Set Grid Simulator to have a starting point voltage equal to the grid independent output voltage of the fuel cell power plant.
3. The time spent at each step shall be one minute.
4. Increase the Grid Simulator output voltage by 1vac and remain at each new voltage value for one minute.
5. Increase the Grid Simulator output voltage until the output is 20% higher than the starting voltage of 120VAC per leg, the fuel cell power plant goes grid independent, or the fuel cell power plant shuts down.
6. Reset the Grid Simulator starting voltage and, if necessary, restart the fuel cell power plant.
7. Decrease the Grid Simulator output voltage by 1vac and remain at each new voltage for one minute.
8. Decrease the Grid simulator output voltage until the fuel cell power plant switches from grid connect to grid independent or the fuel cell power plant shuts down.

9. Reset the Grid Simulator to the starting voltage and, if necessary, restart the fuel cell power plant.
10. Repeat Voltage Sag/Surge Test three times to obtain a pattern of repeatability.

Test 3-Neutral Loss Test

1. Equally distribute a total load of 50% of capacity, across both legs of the fuel cell power plant output, if applicable.
2. The Grid Simulator should be set to grid normal operating mode.
3. Initial load bank values will be equal and total 50% of the fuel cell power plants output capabilities. One of the loads shall vary according to the test table.
4. For each set of load values, the neutral shall start in a closed condition, then in the next step open for one minute.
5. The state of the power plant shall be recorded, and if the fuel cell power plant switches from grid connect to grid independent, or shuts down the test shall be considered finished.
6. Repeat Neutral Loss Test three times to obtain a pattern of repeatability.

Test 4-Waveform Distortion/Harmonic Distortion Test

1. Equally distribute a total load of 50% across both legs of the fuel cell power plant output if 240 VAC outlet, if applicable.
2. Run program in Grid Simulator that will create the following increments of harmonic distortion for 1 minute. 5%, 10%, 12.6% and 14.4%.
3. Allow fuel cell to recover between increments of harmonic distortion.
4. Repeat test three times for proof of repeatability.

Test 5-Disconnect Speed Test

This test will be the time duration between grid connect and grid independent when one of the following disturbances occurs: Frequency deviation, voltage sag/surge, waveform/harmonic distortion, loss of one voltage leg, loss of both voltage legs, and neutral loss.

5. Equally distribute a total load of 50% across both legs of the fuel cell power plant output if 240 VAC outlet, if applicable.
6. Using the CDAQ record grid side and load side parameters.
7. Create disturbance that will cause the FCPP to go into Grid Independent mode.
8. Record and graph data showing grid side and load side parameters vs. time.

Data Acquisition Parameters

Table S1. Power grid simulation test, data acquisition parameters.

Electrical Information from CTC Sensors.	Fuel Supply Rate from CTC Sensor	Environmental Information from CTC Sensors
Sampling Rate 10 per second	Sampling Rate 10 per second	Sampling Rate 10 per second
Gross Output, Stack Current	Inlet Fuel Mass Flow	Air Discharge Rate
Net Output Current (AC or DC)		Air Discharge Temperature
Output Voltage (AC or DC)		Ambient Air Temperature
State of Neutral		Fuel Cell Stack Temperature

Table S2. Power grid simulation test, grid simulator feedback data to be recorded.

Frequency Deviation Value State of Neutral	Voltage Sag Percentage % of THD	Voltage Surge Percentage Disconnect Speed (time)
All data collected by the FCPP on board Data Acquisition System		

Table S3. Power grid simulation test, frequency deviation test.

Test #	Total Test Time Minutes	2 Equal Electronic Loads (Watts) 50% of usable output	Grid Simulator Frequency (60HZ)	Power Plant Status Grid Connect/Grid Independent/Shut Down
1	1 min	50% of Capacity	Initial Value Equal to Power Grid Frequency	
2	2 min	50% of capacity	Power Grid freq. + .01 Hz	
3	3 min	50% of capacity	Power Grid freq. + .02 Hz	
4	4 min	50% of capacity	Power Grid freq. + .03 Hz	
5	5 min	50% of capacity	Power Grid freq. + .04 Hz	
6	6 min	50% of capacity	Power Grid freq. + .05 Hz	
7	7 min	50% of capacity	Power Grid freq. + .06 Hz	
8	8 min	50% of capacity	Power Grid freq. + .07 Hz	
9	9 min	50% of capacity	Power Grid freq. + .08 Hz	
10	10 min	50% of capacity	Power Grid freq. + .09 Hz	
11	11 min	50% of capacity	Continue Increments until Power Plant Disconnect	
12	12 min	50% of capacity	Power Grid Frequency	
13	13 min	50% of capacity	Power Grid freq. – .01 Hz	
14	14 min	50% of capacity	Power Grid freq. – .02 Hz	
16	16 min	50% of capacity	Power Grid freq. – .03 Hz	
17	17 min	50% of capacity	Power Grid freq. – .04 Hz	
18	18 min	50% of capacity	Power Grid freq. – .05 Hz	
19	19 min	50% of capacity	Power Grid freq. – .06 Hz	
20	20 min	50% of capacity	Power Grid freq. – .07 Hz	
21	21 min	50% of capacity	Power Grid freq. – .08 Hz	
22	22 min	50% of capacity	Power Grid freq. – .09 Hz	

Test #	Total Test Time Minutes	2 Equal Electronic Loads (Watts) 50% of usable output	Grid Simulator Frequency (60HZ)	Power Plant Status Grid Connect/Grid Independent/Shut Down
23	23 min	50% of capacity	Power Grid freq.–0.10 Hz	
24+	24 min	50% of capacity	Continue Increments until Power Plant Disconnect	

Table S4. Power grid simulation test, voltage surge/sag test.

Test #	Total Test Time Minutes	2 Equal Electronic Loads (Watts) 50% of usable output	Grid Simulator Output Voltage	Power plant Status Grid Connect/Grid Independent/Shutdown
1	1 min	50% of capacity	Normal Output Voltage	
2	2 min	50% of capacity	NOV + 1vac	
3	3 min	50% of capacity	NOV + 2vac	
4	4 min	50% of capacity	NOV + 3vac	
5	5 min	50% of capacity	NOV + 4vac	
6	6 min	50% of capacity	NOV + 5vac	
7	7 min	50% of capacity	NOV + 6vac	
8	8 min	50% of capacity	NOV + 7vac	
9	9 min	50% of capacity	NOV + 8vac	
10	10 min	50% of capacity	NOV + 9vac	
11	11 min	50% of capacity	NOV + 10vac	
12	12 min	50% of capacity	NOV + 11vac	
13+	13 min	50% of capacity	Continue Increments until Power Plant Disconnect	
14	14 min	50% of capacity	Normal Output Voltage	
15	15 min	50% of capacity	NOV – 1vac	
16	16 min	50% of capacity	NOV – 2vac	
17	17 min	50% of capacity	NOV – 3vac	
18	18 min	50% of capacity	NOV – 4vac	
19	19 min	50% of capacity	NOV – 5vac	
20	20 min	50% of capacity	NOV – 6vac	
21	21 min	50% of capacity	NOV – 7vac	
22	22 min	50% of capacity	NOV – 8vac	
23	23 min	50% of capacity	NOV – 9vac	
24	24 min	50% of capacity	NOV – 10vac	
25	25 min	50% of capacity	NOV – 11vac	
26	26 min	50% of capacity	NOV – 12vac	
27+	27 min	50% of capacity	Continue Increments until Power Plant Disconnect	

Table S5. Power grid simulation test, neutral loss test.

Test #	State of Neutral	Neutral Open Time	Neural Closed Time Seconds	Total Time Minutes/Seconds	Load Bank 1 Watts	Load Bank 2 Watts	Power Plant Status Grid Connect/ Grid Independent/ Shutdown
1	Closed		15	:15	1500	1500	
2	Open	60		1:15	1500	1500	
3	Closed		15	1:30	1500	1400	
4	Open	60		2:30	1500	1400	
5	Closed		15	2:45	1500	1300	
6	Open	60		3:45	1500	1300	
7	Closed		15	4:00	1500	1200	
8	Open	60		5:00	1500	1200	
9	Closed		15	5:15	1500	1100	
10	Open	60		6:15	1500	1100	
11	Closed		15	6:30	1500	1000	
12	Open	60		7:30	1500	1000	
13	Closed		15	7:45	1500	900	
14	Open	60		8:45	1500	900	
15	Closed		15	9:00	1500	800	
16	Open	60		10:00	1500	800	
17	Closed		15	10:15	1500	700	
18	Open	60		11:15	1500	700	
19	Closed		15	11:30	1500	600	
20	Open	60		12:30	1500	600	
21	Closed		15	12:45	1500	500	
22	Open	60		13:45	1500	500	
23	Closed		15	14:00	1500	400	
24	Open	60		15:00	1500	400	
25	Closed		15	15:15	1500	300	
26	Open	60		16:15	1500	300	
27	Closed		15	16:30	1500	200	
28	Open	60		17:30	1500	200	
29	Closed		15	17:45	1500	100	
30	Open	60		18:45	1500	100	
31	Closed		15	19:00	1500	0	
32	Open	60		20:00	1500	0	
33	Closed				1500	1500	

REPORT DOCUMENTATION PAGE					Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) 10-2004		2. REPORT TYPE Final		3. DATES COVERED (From – To)		
4. TITLE AND SUBTITLE Phosphoric Acid Fuel Cells: Test and Evaluation				5a. CONTRACT NUMBER		
				5b. GRANT NUMBER		
				5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) Robert J. Unger, Scott Kenner, Michael J. Binder, and Franklin H. Holcomb				5d. PROJECT NUMBER MIPR		
				5e. TASK NUMBER		
				5f. WORK UNIT NUMBER 006G7B		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL) PO Box 9005 Champaign, IL 61826-9005				8. PERFORMING ORGANIZATION REPORT NUMBER ERDC/CERL TR-04-21		
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Director, Defense, Research, and Engineering (ODDR&E) 1777 N. Kent Suite 9030 Rosslyn, VA 22209				10. SPONSOR/MONITOR'S ACRONYM(S) ODDR&E		
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.						
13. SUPPLEMENTARY NOTES Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.						
14. ABSTRACT Fuel cell power plants can provide improvements in energy conservation and reduced environmental impacts for many DOD applications. Currently, the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC/CERL) Fuel Cell Technology Program facilitates the development of Fuel Cell Technology. This work provided testing and evaluations of fuel cells in support of life-cycle-cost reduction and performance improvement goals. This program also undertook to provide the capability for independent design assessments of alternative technology fuel cell system configurations and components to achieve lower life cycle cost either through reduced capital cost, reduced operation and maintenance (O&M) costs, or increased performance and reliability.						
15. SUBJECT TERMS fuel cells energy conservation energy efficient lifecycle costs power plants						
16. SECURITY CLASSIFICATION OF:				17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 184	19a. NAME OF RESPONSIBLE PERSON Franklin H. Holcomb
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified	19b. TELEPHONE NUMBER (in- clude area code) (217) 373-5864			